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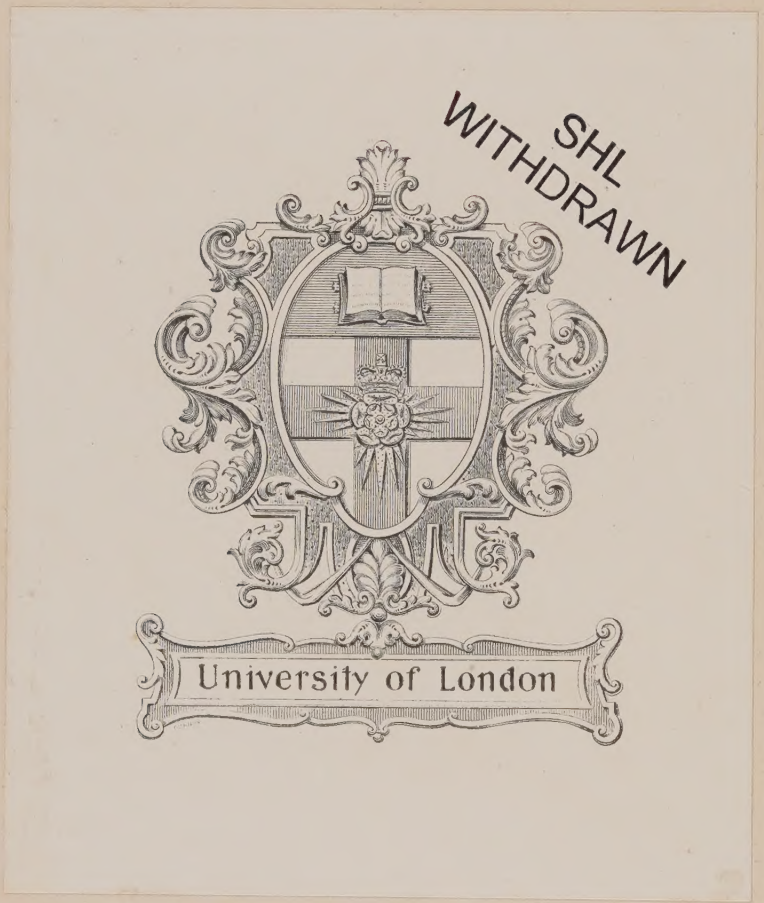

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INTERNATIONAL CRITICAL TABLES
OF
NUMERICAL DATA
PHYSICS, CHEMISTRY AND TECHNOLOGY

VOLUME VI

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INTERNATIONAL CRITICAL TABLES
OF
NUMERICAL DATA,
PHYSICS, CHEMISTRY AND TECHNOLOGY

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Academy of Sciences

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PREFACE TO VOLUMES VI AND VII

At an early stage in the development of the project it became necessary to determine the size of International Critical Tables in order that the requisite financial estimates might be prepared. At that time it was estimated that 2500 pages would suffice, and on this figure the financial requirements of the editorial office and the selling price of the work were based. In the course of the preparation of Volume IV it became apparent that 2500 pages would be insufficient, this being due largely to the phenomenal increase, during the last decade, in the amount of scientific work published.

To the problem thus presented to the Editorial Board only three possible solutions appeared: (1) To eliminate a large proportion of the data in each of the unpublished chapters, thus destroying entirely the completeness aimed for and promised; (2) to omit a considerable number of chapters in order to preserve the completeness of those selected for publication; (3) to expand the publication program to the extent of two additional volumes and to raise the considerable sum of money required to finance the publication of these additional volumes at the same subscription price per volume as the original five. The third solution appeared to be the only logical one.

Through the generous financial support of the Research Corporation, the Chemical Foundation, and the United States Steel Corporation, it has become possible to finance the publication of Volumes VI and VII and thus to carry out the editorial program without sacrifice of completeness.

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J-PHENOMENON IN X-RAYS

C. G. Barkla

As the wave-length (λ) of the homogeneous (unifrequent) beam of X-rays incident upon a thin sheet of absorbing substance is varied, the absorption by the sheet varies discontinuously at certain values of λ. These absorption edges (or occasionally lines) are sharply defined, and correspond to the frequency required to excite the characteristic radiation (K, L, M, etc.) of the absorber.

When the incident beam is heterogeneous (multifrequent) and its "effective" λ is varied, similar sharp discontinuities in the absorption may occur. The "effective" λ is here defined as the λ of that unifrequent radiation for which the ionization produced in a short air-electroscope is reduced to one-half its value by such a thickness of Al as will produce the same reduction in the ionization of the incident multifrequent beam. It may be specified either in Ångstrom units, or by the "effective" mass-absorption-coefficient (μ/ρ) for the incident beam, as determined by the equation $e^{-\mu x} = 0.5$, where x is the thickness of Al required to reduce the ionization to 0.5 its value; ρ = density of Al. It must be emphasized that a discontinuity is not associated with either the minimum λ or the λ of maximum intensity of the incident beam, but with some kind of average for the whole beam—possibly analogous to temperature. Also neither the "effective" $(\mu/\rho)_{Al}$, nor "effective" λ, is an absolute constant in a given substance; it varies somewhat with other factors for the radiation, which are not yet measurable. The critical "effective" $(\mu/\rho)_{Al}$ and "effective" λ are thus approximate only. They are only tentative and cannot precisely express the complex quantity involved.

What appear to be distinct series (J_1, J_2 . . .) of discontinuities have been observed. Later work has shown that under certain conditions, intermediate discontinuities occur (4). It is *possible* that a true measure of the fundamental factor involved will show the critical values for one series to be identical in various substances.

Only tentatively then is the following table given.

J-Absorption Edges (1, 2, 3, 4)

$(\mu/\rho)_{0.5}$ = "effective" mass absorption coefficient in Al for the multifrequent radiation corresponding to the edge; λ_e = wavelength of unifrequent radiation for which mass absorption coefficient of Al = $(\mu/\rho)_{0.5}$. "Effective" coefficient is computed from thickness required to reduce ionization by 50 %. Unit of $(\mu/\rho)_{0.5}$ = 1 cm²/g; of λ = 1 Ångstrom.

Absorber	$(\mu/\rho)_{0.5}$				λ_e			
	J_1	J_2	J_3	$J_{4,5}$*	J_1	J_2	J_3	$J_{4,5}$*
C6			1.05				0.39	
N7		2.5				0.55		
O8	>4	2.2	0.83	0.47	>0.66	0.5	0.355	0.28
Al13	3.8	1.9	0.7	0.34	0.63	0.49	0.335	0.23
Si14		1.85				0.493		
S16		1.7				0.48		
Cu29	3.5	1.46	0.6		0.61	0.45	0.315	
Ag47	2.0	1.4			0.5	0.45		
Pt78			0.57				0.305	
Au79			0.54				0.30	

* J_4, J_5, or J_4 and J_5.

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(1) Barkla, *S*, **49**: 1033; 25. (2) Barkla and Khastgir, *S*, **49**: 251; 25. **50**: 1115; 25. (3) Barkla and Mackenzie, *S*, **1**: 542; 26. (4) Barkla and Watson, *S*, **2**: 1122; 26.

POLARIZATION OF X-RAYS

C. G. Barkla

The polarization of primary X-rays was discovered by Barkla in 1904 (1, 2), and in 1906 (3) he found that certain scattered X-rays are almost completely polarized: the ionization method of intensity measurement was used. By photographic methods it has been shown that heterogeneous primary radiation from a carbon target (9), and heterogeneous scattered radiation (8) are polarized, that the homogeneous characteristic radiation after reflection in a direction at 90° to the incident radiation is fairly completely polarized (11), and that characteristic radiation excited by homogeneous radiation is unpolarized (11). In order to determine the amount of polarization, the beam is intercepted by a suitable scattering substance, and the variation in the intensity of the rays that are scattered in directions perpendicular to the incident beam is determined. With a variation of 360° in the direction of scattering, this intensity passes through 2 maxima and 2 minima; the difference in azimuth from a maximum (M) to a minimum (m) is 90°. If the incident beam is compounded of unpolarized radiation of intensity R, and of plane polarized radiation of intensity P, then $M/m = (P + 0.5R)/(0.5R)$. Hence, fraction (p) which is plane polarized is $P/(P + R) = (M - m)/(M + m)$ and the relative component variation (v) is $(M - m)/M = P/(P + 0.5R)$.

Degree of Polarization of X-Rays

$P[R]$ = intensity of plane polarized [unpolarized] constituent; $p = P/(P + R)$; $v = P/(P + 0.5R)$. $H[S]$ indicates that incident radiation is hard [soft]. Except where the contrary is indicated, the rays are heterogeneous. Unit of v and of p = 1 %.

Rays	Source	v		p		Lit.
		H	S	H	S	
Primary.....	Gas tube*	6	20	3	11	(2, 4)
Primary.....	Gas tube	4	28	2	16	(6)
Primary.....	Gas tube	7	21	4	12	(12)
Primary.....	Gas tube		43†		27†	(12)
Primary.....	Coolidge tube	8	23	4	13	(10)
Primary.....	Coolidge tube	16.5‡	2§	9‡	1§	(10)
Scattered‖.....	Carbon	$70 + x$		$54 + y$		(3)
Scattered‖.....	$\lambda = 0.25$ Å	$95 + x'$		$90 + y'$		(7)
Characteristic...		0		0		(3, 4)

* The constituents of higher frequency are the more completely polarized.
† From Ni target.
‡ $\lambda = 0.3$ Å.
§ $\lambda = 1$ Å.
‖ Data refer to rays scattered in a direction perpendicular to primary radiation. The true polarization is greater than that actually measured; correction factors x and y are necessary owing to obliquity of rays in beams of finite cross-section. Hence polarization of scattered rays in stated direction is approximately complete; *i.e.*, 100 %.

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(1) Barkla, *58*, **69**: 463; 04. (2) Barkla, *62*, **204**: 467; 05. (3) Barkla, *5*, **77**: 247; 06. (4) Barkla, *3*, **15**: 288; 08. (5) Barkla and Sadler, *3*, **16**: 550; 08. (6) Bassler, *8*, **28**: 808; 09. (7) Compton and Hagenow, *2*, **18**: 97; 21. (8) Haga, *8*, **23**: 439; 07. (9) Herweg, *8*, **29**: 398; 09. (10) Kirkpatrick, *2*, **22**: 226; 23. (11) Mark and Szilard, *96*, **35**: 743; 26. (12) Vegard, *5*, **83**: 379; 10.

ELECTRONIC RADIATION EXCITED BY X-RAYS

Maurice de Broglie and Jean Thibaud

For unexplained symbols, *see* Vol. I, p.16

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Perrin (53) and, later, Curie and Sagnac (27) observed that all kinds of matter emit electrons (28) when irradiated by X-rays. There are two distinct classes of these electrons: Those of one class have a high velocity when emitted and are often called β-rays, and those of the other have a much lower velocity and are often called δ-rays. The latter are much the more numerous (65); 85% of the electrons emitted by gold leaf irradiated by X-rays from a Coolidge tube with a tungsten target have velocities lower than that corresponding to 2 volt.

Wilson (75) and Auger (3, 4) have shown by the fog method that very often a single atom will emit a group of several electrons. In such cases, the X-ray quantum causes initially the ejection of an electron from (*e.g.*) the *K*-level. An *L*-electron replaces it and there results an emission of a $K\alpha$-ray; this detaches an electron from the *L*-level of the same atom. Two *L*-rays are thus produced and, in their turn, ionize the more exterior levels. The initial quantum releases 4 photoelectrons. Thus it may be that the energy is not emitted as electromagnetic radiation but within the atom is transformed to the electronic form.

VELOCITY OF THE EMITTED ELECTRONS

High Velocity Electrons.—Among the electrons emitted with high velocity are electrons of all velocities, within a certain range, forming a "continuous spectrum" which corresponds, at least partially, to that of the exciting X-rays. There are also groups of electrons having essentially a common velocity which varies discretely from group to group. The common velocity of each of these groups (*v.* Table 1) has been found (19, 31, 41, 58, 64) to satisfy the generalized Einstein relation (30) $\mathbf{m}_0\mathbf{c}^2\{(1-\beta^2)^{-\frac{1}{2}}-1\} = \mathbf{h}\nu - w_0$, where $\beta \equiv v/\mathbf{c}$, v = velocity of the electron when emitted, ν = frequency of the exciting X-rays, w_0 = work done by the electron in escaping from the atom. The value of w_0 depends upon the structure of the atom and the energy-level from which the electron is ejected. Values of w_0 may be determined from ionization potentials (V_0) (*q.v.*, p. 69) by the relation $\mathbf{e}V_0 = w_0$, or from critical absorption-limits, or frequency limits of characteristic X-radiation (*v.* Emission of X-rays, p. 23), by the simple Einstein relation $w_0 = \mathbf{h}\nu_0$, where ν_0 = frequency limit. Some authors (6, 7); *cf.* (9, 12, 35, 50, 61, 71, 72) have observed in the emission from Ag and Sn a few electrons for which $w_0 = 0$. For gases, w_0 is in all cases very small, rare gases of high atomic numbers excepted.

If the X-rays are complex, there will be a group velocity corresponding to each wave-length and to each absorption-level of the atom; and superposed upon this emission will be another, arising from the fluorescent (characteristic) X-radiation emitted by the atoms which are ionized by the primary rays. On passing through a magnetic field these groups are spread out into a magnetic spectrum (19).

The Einstein relation, having been established in many cases, may be used for determining, from the observed velocity of the emitted electrons, (1) the energy corresponding to unknown levels (13, 45) and (2) the wave-length of the exciting radiation (31, 69).

Robinson (57) has discovered an interesting relation involving the electronic emission from the various subdivisions of a given level. The greatest number of electrons comes from the subdivision of smallest energy, (*e.g.*, L_{III}), provided that the critical frequency (L) of the element is not too much smaller than the frequency of the incident X-rays. But as the critical frequency is successively reduced by passage from element to element (*i.e.*, as it differs more and more from that of the X-rays), the maximum of intensity of the secondary electrons is displaced towards the subdivision of greatest energy (L_I).

From observations with gases Whiddington (71) found that when an electron has passed a distance x through matter its velocity has been reduced from v_0 to v_x, such that $v_0^4 - v_x^4 = ax$, where a is a constant characteristic of the matter. If the unit of a is 10^{40} cm^3/sec^4, the value of a for air is 2, for Al is 732, and for Au is 2540. If R = range (unit = 1 cm) in air (t = 20°C, p = 1 atm.) of electrons which have a velocity which may be annulled by a potential difference $= V$ (unit = 1 volt), then (Wilson (74, 75)) $V = 21\,000\sqrt{R}$ if $0.1 < R < 1.5$; this agrees well with Whiddington's expression.

TABLE 1.—ENERGY (E) OF ELECTRONS EMITTED BY ELEMENTARY SUBSTANCES UNDER THE ACTION OF X-RAYS

Observed energy: $E = \mathbf{e}V$; calculated energy: $\mathbf{e}V' = \mathbf{h}\nu - w_0$; Rad. = exciting radiation; Lev. = energy-level from which electron is ejected. X-rays are generated in a Coolidge tube with target of the material indicated. Estimated precision and observer: Cu target (56), 0.5%; Rh target (19), 2%; Rh target (73), 1.5%; W target (19), 2%. Unit of V and V' = 1 volt.

V	Rad.	Lev.	V'
	Ag; Z = 47; target = Cu		
4 237	$K\alpha_1$ Cu	L_1	
3 152	$K\alpha_1$ Cu	L_2	
4 695	$K\alpha_1$ Cu	L_3	
7 382	$K\alpha_1$ Cu	$M_{1,2}$	
7 498	$K\alpha_1$ Cu	M_3	
7 708	$K\alpha_1$ Cu	$M_4 - M_5$	
8 006	$K\alpha_1$ Cu	N	
	Ag; Z = 47; target = W		
17 940	$K\alpha$ Ag	L	18 020
20 900	$K\beta$ Ag	L	20 860
32 760	$K\alpha$ W	K	32 880
40 990	$K\beta$ W	K	41 520
55 140	$K\alpha$ W	L	54 730
	Al; Z = 13; target = Rh (73)		
18 440	$K\alpha$ Rh	K	18 600
20 660	$K\beta$ Rh	K	21 110
	As; Z = 33; target = Rh (73)		
9 135	$K\alpha$ As	L	9 094
10 330	$K\beta$ As	L	10 290
11 110	$K\beta$ As		11 730
18 190	$K\alpha$ Rh	L	18 720
20 860	$K\beta$ Rh	L	21 230
23 170	$K\beta$ Rh		22 670
	Au; Z = 79; target = Cu		
4 595	$K\alpha_1$ Cu	M_1	
4 875	$K\alpha_1$ Cu	M_2	
5 291	$K\alpha_1$ Cu	M_3	
5 756	$K\alpha_1$ Cu	M_4	
5 843	$K\alpha_1$ Cu	M_5	
7 296	$K\alpha_1$ Cu	$N_1 - N_3$	
7 508	$K\alpha_1$ Cu		
7 724	$K\alpha_1$ Cu	$N_{4,5}$	
8 006	$K\alpha_1$ Cu	$N_{6,7}$, O	
	Ba; Z = 56; target = Cu		
2 025	$K\alpha_1$ Cu	L_1	
2 421	$K\alpha_1$ Cu	L_2	
2 801	$K\alpha_1$ Cu	L_3	
3 613	$K\alpha_1$ Cu	*	
4 331	$K\alpha_1$ Cu	*	
6 733	$K\alpha_1$ Cu	M_1	
6 880	$K\alpha_1$ Cu	M_2	
6 960	$K\alpha_1$ Cu	M_3	
7 239	$K\alpha_1$ Cu	$M_{4,5}$	
7 464	$K\alpha_1$ Cu	(?)KO†	

* Fluorescence, $L - M$. † KO = K-radiation of oxygen.

TABLE 1.—(*Continued*)

V	Rad.	Lev.	V′
	Ba; Z = 56; target = Cu.—(*Continued*)		
7 584	$K\alpha_1$ Cu	(?)*KC*‡	
7 842	$K\alpha_1$ Cu	$N_1 - N_3$	
8 036	$K\alpha_1$ Cu	$N_4 - O$	
	Ba; Z = 56; target = W		
26 090	$K\alpha$ Ba	L	25 600
30 290	$K\beta$ Ba	L	30 000
53 500	$K\alpha$ W	L	52 430
	Bi; Z = 83; target = Cu		
4 014	$K\alpha_1$ Cu	M_1	
4 339	$K\alpha_1$ Cu	M_2	
4 844	$K\alpha_1$ Cu	M_3	
5 317	$K\alpha_1$ Cu	M_4	
5 435	$K\alpha_1$ Cu	M_5	
7 065	$K\alpha_1$ Cu	N_1	
7 204	$K\alpha_1$ Cu	N_2	
7 340	$K\alpha_1$ Cu	N_3	
7 513	$K\alpha_1$ Cu	N_4	
7 579	$K\alpha_1$ Cu	N_5	
7 911	$K\alpha_1$ Cu	$N_{6,7}$, O	
	Bi; Z = 83; target = Rh (73)		
8 518	$L\alpha$ Bi	M	8 395
10 700	$L\beta$ Bi	M	10 700
12 340	$L\gamma$ Bi	M	13 000
15 140	$L\gamma$ Bi		15 310
19 710	$K\alpha$ Rh	N	19 920
22 140	$K\beta$ Rh	N	22 430
	Cu; Z = 29; target = Cu		
6 920	$K\alpha_1$ Cu	L_1	
7 086	$K\alpha_1$ Cu	$L_2 - L_3$	
7 943	$K\alpha_1$ Cu	M	
	Cu; Z = 29; target = Rh (73)		
7 078	$K\alpha$ Cu	L	7 119
7 942	$K\beta$ Cu	L	7 983
8 929	$K\beta$ Cu		8 888
11 110	$K\alpha$ Rh	K	11 230
12 880	$K\beta$ Rh	(?)K	13 740
18 970	$K\alpha$ Rh	L	19 260
20 660	$K\beta$ Rh	L	21 770
22 720	$K\beta$ Rh		22 670
	Cu; Z = 29; target = Rh (19)		
11 360	$K\alpha_1$ Rh	K	11 230
13 660	$K\beta_1$ Rh	K	13 740
19 260	$K\alpha_1$ Rh	L	19 180
21 650	$K\beta_1$ Rh	L	21 690
	I; Z = 53; target = Cu		
2 841	$K\alpha_1$ Cu	L_1	
3 200	$K\alpha_1$ Cu	L_2	
3 463	$K\alpha_1$ Cu	L_3	
6 947	$K\alpha_1$ Cu	M_1	
7 130	$K\alpha_1$ Cu	$M_2 - M_3$	
7 399	$K\alpha_1$ Cu	$M_4 - M_5$	
7 906	$K\alpha_1$ Cu	N, O	
	I; Z = 53; target = W		
23 130	$K\alpha$ I	L	22 920
27 320	$K\beta$ I	L	26 460
54 650	$K\alpha$ W	L	53 080
	Mo; Z = 42; target = Cu		
5 157	$K\alpha_1$ Cu	L_1	
5 411	$K\alpha_1$ Cu	L_2	
5 509	$K\alpha_1$ Cu	L_3	
7 646	$K\alpha_1$ Cu	(?)M_3	
7 783	$K\alpha_1$ Cu	(?)M_5	
7 989	$K\alpha_1$ Cu	(?)N	

‡ *KC* = *K*-radiation of carbon.

V	Rad.	Lev.	V′
	Mo; Z = 42; target = Rh (73)		
14 860	$K\alpha$ Mo	L	14 980
20 210	$K\beta$ Mo	L	17 120
19 550	$K\beta$ Mo		19 590
	Mo; Z = 42; target = W		
14 070	$K\alpha$ Mo	L	14 690
16 630	$K\beta$ Mo	L	16 910
38 680	$K\alpha$ W	K	38 350
	Pb; Z = 82; target = Cu		
4 179	$K\alpha_1$ Cu	M_1	
4 468	$K\alpha_1$ Cu	M_2	
4 954	$K\alpha_1$ Cu	M_3	
5 442	$K\alpha_1$ Cu	M_4	
5 557	$K\alpha_1$ Cu	M_5	
7 367	$K\alpha_1$ Cu	$N_{1,3}$	
7 605	$K\alpha_1$ Cu	$N_{4,5}$	
7 919	$K\alpha_1$ Cu	$N_{6,7}$, O	
	Rh; Z = 45; target = W		
16 790	$K\alpha$ Rh	L	16 870
19 420	$K\beta$ Rh	L	19 510
35 800	$K\alpha$ W	K	35 180
	Sb; Z = 51; target = W		
21 890	$K\alpha$ Sb	L	21 930
25 270	$K\beta$ Sb	L	25 350
28 810	$K\beta$ Sb	M	28 850
	Se; Z = 34; target = Rh (19)		
8 148	$K\alpha_1$ Rh	K	7 777
9 053	$K\alpha_1$ Se	L	9 547
10 290	$K\beta$ Rh	K	10 370
	$K\beta$ Se	L	10 780
17 780	$K\alpha_1$ Rh	L	18 560
20 660	$K\beta$ Rh	L	21 070
	Sn; Z = 50; target = Cu		
3 563	$K\alpha_1$ Cu	L_1	
3 861	$K\alpha_1$ Cu	L_2	
4 092	$K\alpha_1$ Cu	L_3	
7 146	$K\alpha_1$ Cu	M_1	
7 317	$K\alpha_1$ Cu	$M_{2,3}$	
7 550	$K\alpha_1$ Cu	$M_4 - M_5$	
7 928	$K\alpha_1$ Cu	N	
	Sn; Z = 50; target = W		
20 580	$K\alpha$ Sn	L	20 820
23 700	$K\beta$ Sn	L	24 110
29 220	$K\alpha$ W	K	28 810
36 640	$K\beta$ W	K	37 410
53 170	$K\alpha$ W	L	53 990
	Sr; Z = 38; target = Cu		
5 793	$K\alpha_1$ Cu	L_1	
6 001	$K\alpha_1$ Cu	L_2	
6 055	$K\alpha_1$ Cu	L_3	
7 473	$K\alpha_1$ Cu	(?)*KO**	
7 703	$K\alpha_1$ Cu	(?)M	
8 026	$K\alpha_1$ Cu	(?)N	
	Sr; Z = 38; target = Rh (73)		
12 020	$K\alpha$ Sr	L	12 180
13 740	$K\beta$ Sr	L	13 870
15 230	$K\beta$ Sr		15 840
17 530	$K\alpha$ Rh	L	18 190
16 950	$K\beta$ Rh	L	20 700
22 390	$K\beta$ Rh		22 670
	Sr; Z = 38; target = W		
11 520	$K\alpha$ Sr	L	12 020
13 500	$K\beta$ Sr	L	13 790

* *KO* = *K*-radiation of oxygen.

TABLE 1.—(*Continued*)

V	Rad.	Lev.	V'
	W; Z = 74; target = Cu		
5 206	$K\alpha_1$ Cu	M_1	
5 465	$K\alpha_1$ Cu	M_2	
5 761	$K\alpha_1$ Cu	M_3	
6 148	$K\alpha_1$ Cu	M_4	
6 226	$K\alpha_1$ Cu	M_5	
7 605	$K\alpha_1$ Cu	$N_1 - N_3$	
7 798	$K\alpha_1$ Cu	$N_4 - N_5$	
8 037	$K\alpha_1$ Cu	$N_6 - N_7 - O$	
	W; Z = 74; target = Rh (73)		
6 749	$L\alpha$ W	M	6 666
8 353	$L\beta$ W	M	8 312
9 917	$L\gamma$ W	M	9 958
11 400	$L\gamma$ W		11 600
18 310	$K\alpha$ Rh	M	18 520
20 330	$K\alpha$ Rh		20 160
22 390	$K\beta$ Rh		22 670
	Yb; Z = 70; target = W		
41 640	$K\alpha$ Yb	L	42 840
48 560	$K\beta$ Yb	L	49 870
	Zn; Z = 30; target = Rh (73)		
7 777	$K\alpha$ Zn	L	7 613
8 847	$K\beta$ Zn	L	8 559
9 629	$K\beta$ Zn		9 547
10 700	$K\alpha$ Rh	K	10 990
13 090	$K\beta$ Rh	(?)K	13 500
18 760	$K\alpha$ Rh	L	19 180
	Zn; Z = 30; target = W		
7 407	$K\alpha$ Zn	L	7 366
8 395	$K\beta$ Zn	L	8 312

Low Velocity Electrons.—The velocity with which the slow electrons are emitted is independent of the nature of the radiator (63). Shearer (63) attributes these electrons to a secondary effect of the rapid electrons and Simons (65, 66) to the recoil of the atoms from which the rapid electrons are ejected; the latter notes a relation between the distribution of the velocities of these electrons (corresponding to T = 11 000°K) and that of thermions in a hot body. Their origin may be associated with the diffusion of the incident X-rays, as Compton (24) has shown that the weakly bound electrons can be expelled by a quantum of radiation.

NUMBER OF ELECTRONS EMITTED

The total number (n_e) of electrons emitted per second is intimately related to the absorption of the X-rays by the substance. The law of fluorescent absorption deduced by Bragg and Peirce, $\tau A/\rho = CZ^4\lambda^3$, where τ = coefficient of fluorescent absorption (coefficient of absorption after correction for scattering), ρ = density, λ = wave-length, A = atomic weight, C = constant of proportionality, and Z = atomic number of radiator = number of electrons per atom, has also been deduced from thermodynamics and the quantum theory (20) and by means of the principle of correspondence (43). It indicates (21) that the probability of emission of an electron from an atom of atomic number Z under action of radiation of intensity (I) and frequency (ν) is proportional to $Z^4\nu^{-4}I$. Jauncey (38) has recently announced the same result in a somewhat different form. Throughout this report I is defined as proportional to the total number of ions produced, per second and per unit of solid angle, by complete absorption of the radiation in air. The experimental results are discordant, as follows:

Variation with Emitting Substance.—The value of n_e increases with Z (Laub (44)), is proportional to Z^4 (Moore (49)), is proportional to Z (Whiddington (73)). Shearer (63) states that for Al, Fe, Ni, Cu, Ag, Sn, Au, Pb and Bi, the number (N_e) of electrons excited in an atom is $N_e = K(Z - 10)$, and consequently n_e is proportional to the number of electrons contained in an atom. Actually, we observe only those which escape from the body and the law of variation of the absorption (of the electrons) with the velocity is uncertain. This may explain the discordances.

For salts and gases, n_e increases with the molecular weight; for CH_3I, it is 100 times as great as for air.

Variation with the Radiation.—For a given I, n_e decreases as penetration increases, $n_e \propto V^{-\frac{1}{2}}$ (Shearer (63)), where V = tube voltage. Hoepner (34) found n_e decreased more rapidly than I; Herweg and Mie (33) found $n_e \propto I$ even when I was very small. To obtain concordant results, the number of electrons belonging to each group of uniform velocity should be measured individually, and also the number composing the adjacent portion of the continuous spectrum, and these should be correlated with the distribution of I in the spectrum of the exciting radiation. This has not been done.

DIRECTION OF EMISSION

Solids.—For solids, the number of electrons emitted in the direction of propagation of the X-rays exceeds that emitted in the opposite direction (10, 18, 25, 42, 47, 54, 62, 68). This dissymmetry is independent of Z and of the physical state of the radiator (51); from his experiments with Cu, Wilson (74, 75) concludes that it arises from a curvature in the trajectories of the electrons, rather than a dissymmetry in emission.

Gases.—*Long Range Electrons.*—A polarization of the X-rays leads to a marked lateral concentration of the long range emitted electrons, in the direction of the electric vector of the X-rays (22, 74, 75). The emitted electrons are also concentrated longitudinally in a privileged direction making an acute angle with the direction of propagation of the X-rays. In air, Wilson (74, 75) found the privileged direction was 45° to the X-rays, 20 % of the electrons were ejected at 90° (result of polarization) and a few had a backward component. Using polarized X-rays, Bubb (22) found ½ had a forward component, ⅙ had a backward component, and ⅓ were almost at 90°. In H, Auger (1) found privileged direction at 80° and the number of electrons with a forward component was about twice as great as that of those with a backward one. For halogens, the longitudinal dissymmetry increases in the order I, Br, Cl, F, and possibly decreases as the tube-voltage decreases (16).

Recent experiments (2, 5, 17, 22) by the fog method show that the most probable direction of ejection of a photoelectron is nearly that of the electric vector of the incident wave but there is an additional component in the direction of propagation of the wave. This component increases when either the potential difference applied to the tube or the frequency of the X-rays is increased (4). When the X-rays are polarized there is a very great preponderance in the number of photoelectrons in the plane containing the electric vector of the incident rays (22). Many attempts to account theoretically for this distribution have been made. Those of Bubb (23); *cf.* (17) and of Auger and Perrin (5) agree qualitatively with the observations, but neither completely agrees quantitatively.

The origin of the path of a swift electron is marked by a cloud of ions due to the simultaneous emission of a slow electron (1). The initial portion of the path of a swift electron is straight, but deviations of the following 3 kinds become more and more frequent as the velocity decreases: (*a*) A sudden deflection through a large angle, frequently 180°, due to the electron's passing very near an atomic nucleus. (*b*) A sudden deflection, which may attain 45°, due to a collision in such a manner with another electron that the latter is ejected, generally at 90° to the path of the primary electron, with sufficient velocity to give rise to a bifurcated or "branch

track" of ions. (*c*) A progressively curved path due to an accumulation of small deflections of type (*b*) or, according to some authors, to a gyroscopic action of the electron. The end of the path is marked by a small cloud of ions. Wilson (74, 75) thinks he has shown that, when a tertiary path is grafted upon the main trajectory the two emissions, at the point where the deflection occurs, occur at appreciably different times (0.001 sec). (This conclusion is similar to Bearden's (8) that the emission of fluorescent X-rays occurs 10^{-5} sec after the arrival of the exciting radiation.) Along the entire path there are groups of one or several pairs of ions, apparently due to short and ramified paths of type (*b*).

Short Range Electrons.—Under action of X-rays of sufficiently high frequency a secondary emission of electrons of very short range ("fish-tracks" of 1 to 2 mm, "sphere-tracks" of a few tenths of a mm), which form a distinct class and do not satisfy the quantum relation, has been observed (15, 74, 75) in air, H and He. They are ejected nearly in the direction of propagation of the X-rays. At a tube voltage of 20 kv, there are no fish-tracks in air, and sphere-tracks are rare, but as the voltage increases both increase rapidly, sphere-tracks become fish-tracks and these increase in range (67), and presently short range electrons are more numerous than long range ones. The origin of these electrons is explained by the quantum theory of diffusion of radiation as developed by Compton and Debye; *see also* (24, 39).

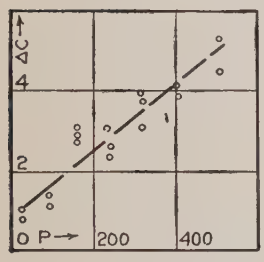

Fig. 1.

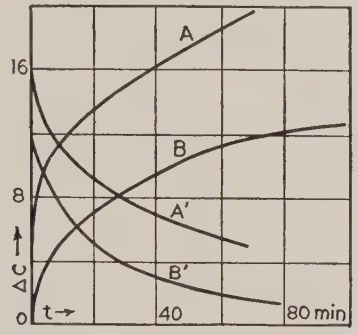

Fig. 2.

Fig. 1.—Effect of pressure (P) upon increase (ΔC) in conductance of a crystal of Se when irradiated by X-rays (48).

Unit of $\Delta C = 10^{-8}$ ohm^{-1}, of $P = 1$ g on area of 0.064 mm^2.

Fig. 2.—Progressive increase (ΔC) in conductance of a crystal of Se during irradiation by X-rays, and its recovery after cessation of irradiation (48).

Pressure = 320 g on area of 0.064 mm^2; initial conductance = 48×10^{-8} ohm^{-1}. Unit of $\Delta C = 10^{-8}$ ohm^{-1}, of time (t) = 1 minute. A = change during irradiation, A' = recovery; B and B' are similar to A and A' but apply to the crystal after it had been fatigued by exposure to γ-rays and had a conductance of 46×10^{-8} ohm^{-1}.

CONDUCTIVITY OF SOLIDS AND LIQUIDS EXPOSED TO X-RAYS

On exposure to X-rays, the conductivity of solids and liquids, especially of dielectrics, is temporarily increased (11, 14, 26, 36, 40, 70). The increases in the conduction of a crystal of Se after an exposure of 1 min to light (λ = 7000 Å), to X-rays (λ = 1.5 Å) and to γ-rays (λ = 0.03 to 0.4 Å) were 33.2, 58.5, and 108.9 ohm^{-1} per joule absorbed, respectively (48, 52). For variation with time and pressure, *see* Figs. 1 and 2. The conductivity of a plate of NaCl increases during exposure to X-rays, and gradually decreases after the X-rays are withdrawn; the exposure "activates" the plate for future action of ordinary light (59). The conductivity of S increases considerably under action of X-rays; the increase is proportional to intensity of the radiation and varies with the nature of the rays in same manner as the ionization of air; in the range of potential difference investigated (69 to 204 volt) the conduction satisfies Ohm's law; the conductivity conferred by irradiation is 3 times as great for monoclinic as for rhombohedral sulfur (32). The conductivity of crystals of calcite ($CaCO_3$), of fluorite (CaF_2), and of feldspar is increased by radiation (46), and the property of luminescence, previously reduced by heating, is restored. The apparent charges of a permanently polarized dielectric are temporarily destroyed by exposure to X-rays (29).

Under action of X-rays, insulating liquids acquire a conductivity which satisfies Ohm's law if the potential gradient does not exceed about 700 volt per cm; the value of this conductivity for a certain unstated radiation is given in Table 2. There is no appreciable dissociation of the molecules, *cf.* (37). Recently, del Regno (55) has studied the variation in the electrical resistance of a selenium cell subjected to the radiations from mesothorium, and Ross (60) has studied the increase in the conductivity of solid dielectrics (sulfur, paraffin, ebonite, amber) subjected to X-rays. For action of γ-rays, *see* (36).

Table 2.—Conductivity (C) of Insulating Liquids When Exposed to X-Rays (26, 36)

Quality and intensity of X-rays are not stated, unit of $C = 10^{-4}$ ohm^{-1} cm^{-1}

Formula	Name	C
CCl_4	Carbon tetrachloride	8
CS_2	Carbon disulfide	20
C_5H_{10}	Amylene	14
C_6H_6	Benzene	4
	Liquid air	1.3
	Petroleum ether	15
	Vaseline oil	1.6

LITERATURE

(For a key to the periodicals see end of volume)

(1) Auger, *34*, **177**: 169; 23. **178**: 929; 24. (2) Auger, *34*, **178**: 1535; 24. (3) Auger, *34*, **180**: 65; 25. (4) Auger, *51*, **6**: 205; 25. (5) Auger and Perrin, *34*, **180**: 1742; 25. (6) Barkla and Dallas, *3*, **47**: 1; 24. (7) Barkla and Shearer, *3*, **30**: 745; 15. (8) Bearden, *58*, **113**: 857; 24. (9) Beatty, *3*, **20**: 320; 10.

(10) Beatty, *201*, **15**: 492; 10. (11) Becker, *8*, **12**: 124; 03. (12) Becker, *2*, **22**: 524; 23. (13) Becker, *2*, **24**: 478; 24. (14) Becquerel, *34*, **136**: 1173; 03. (15) Bothe, *96*, **20**: 34, 237; 23. (16) Bothe, *96*, **26**: 59; 24. (17) Bothe, *96*, **26**: 74; 24. (18) Bragg and Porter, *5*, **85**: 349; 11. (19) de Broglie, *34*, **172**: 274, 527, 746, 806; 21. **173**: 1157; 21. *51*, **2**: 265; 21.

(20) de Broglie, *51*, **3**: 33; 22. (21) de Broglie and de Broglie, *34*, **173**: 527; 21. (22) Bubb, *2*, **23**: 137; 24. (23) Bubb, *3*, **49**: 824; 25. (24) Compton and Hubbard, *2*, **23**: 429; 24. (25) Cooksey, *58*, **77**: 509; 08. *3*, **24**: 37; 12. (26) Curie, *34*, **134**: 420; 02. (27) Curie and Sagnac, *51*, **1**: 13; 02. (28) Dorn, *18*, **5**: 595; 00. (29) Eguchi, *219*, **2**: 45; 20.

(30) Einstein, *8*, **17**: 132; 05. (31) Ellis, *5*, **99**: 261; 21. (32) Grebe, *96*, **17**: 295; 23. (33) Herweg and Mie, *8*, **68**: 120; 22. (34) Hoepner, *8*, **46**: 577; 15. (35) Innes, *5*, **79**: 442; 07. (36) Jaffé, *3*, **25**: 257; 08. (37) Janitzky. *96*, **20**: 280; 23. (38) Jauncey, *3*, **48**: 81; 24. (39) Jauncey, *2*, **23**: 580; 24,

(40) Joffé, *3*, **20**: 919; 06. (41) Kang-Fuh Hu, *2*, **11**: 505; 18. (42) Kleemann, *58*, **83**: 339; 10. *5*, **83**: 530; 10. (43) Kramers, *3*, **46**: 836; 23. (44) Laub, *8*, **26**: 712; 08. (45) Ledrus, *34*, **176**: 383; 23. (46) MacKay, *69*, **15**: 3, 95; 21. (47) MacKenzie, *3*, **14**: 176; 07. (48) MacMahon, *2*, **16**: 558; 20. (49) Moore, *5*, **91**: 337; 15.

(50) Moseley, *3*, **27**: 703; 14. (51) Owen, *67*, **30**: 133; 18. (52) Perreau, *34*, **129**: 956; 99. (53) Perrin, *6*, **11**: 496; 97. (54) Philpot, *67*, **26**: 131; 14. (55) del Regno, *22*, **3**: 201; 26. (56) Robinson, *5*, **104**: 455; 23. (57) Robinson, *3*, **50**: 241; 25. (58) Robinson and Rawlinson, *3*, **28**: 277; 14. (59) Röntgen, *8*, **64**: 1; 21.

(60) Ross, *96*, **36**: 18; 26. (61) Sadler, *3*, **19**: 337; 10. (62) Seitz, *8*, **73**: 183; 24. (63) Shearer, *3*, **44**: 793; 22. (64) Simons, *3*, **41**: 120; 21. (65) Simons, *3*, **46**: 473; 23. (66) Simons, *3*, **48**: 250; 24. (67) Skobelzyn, *96*, **24**: 393; 24. **28**: 278; 24. (68) Stuhlman, *3*, **22**: 854; 11. (69) Thibaud, *34*, **178**: 1706; 24. **179**: 165, 815; 24.

(70) Thomson and McClelland, *201*, **9**: 126; 98. (71) Whiddington, *5*, **86**: 360; 12. (72) Whiddington, *5*, **86**: 370; 12. (73) Whiddington, *3*, **43**: 1116: 22. (74) Wilson, *5*, **104**: 1; 23. (75) Wilson, *5*, **104**: 192; 23

CRYSTAL GRATINGS FOR X-RAY SPECTROSCOPY

BERGEN DAVIS

The wave-length of X-rays is usually determined either by means of the ionization spectrometer or by a photographic method. With suitable crystals, the former is probably the more accurate, but it requires uniform reflecting planes sufficiently large to reflect a considerable amount of energy. The photographic method may be used with small irregular crystals and is particularly useful with powdered crystals.

Grating Constant.—The grating constant of a crystal is usually measured in terms of that of either calcite ($CaCO_3$) or rock salt (NaCl), the constant of the standard being calculated from crystal data and other physical constants. Even the best specimens of rock salt are imperfect crystals, the reflecting planes being not uniformly parallel planes throughout any considerable volume of the crystal; also the rocking curves obtained by means of the double X-ray spectrometer are wide (11.1), indicating that the crystal elements are quite imperfect. Calcite (Iceland spar) is much more nearly perfect; for it, the rocking curves are very smooth and narrow (less then $\frac{1}{60}$ of the width of the rock salt curves).

On account of the perfection of its crystal structure, it is recommended that calcite (Iceland spar) be selected as the primary standard in all measurements of the wave-lengths of X-rays; and that the value $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$ cm (at 20°C) be used. This value of d_{100} for calcite is as probable as any other value yet deduced; it is equivalent (27) to $d_{100} = 2.814 \times 10^{-8}$ cm (at 20°C) for rock salt. A large number of measurements have already been made in terms of one or other of these equivalent values.

If a_0 = length of edge of unit crystal form, the observed grating space for the planes (h, k, l) of a face-centered cubic crystal, like rock salt, is $d_{hkl} = a_0/\sqrt{h^2 + k^2 + l^2}$ if h, k, and l are *all odd*, and in all other cases $d_{hkl} = 0.5a_0/\sqrt{h^2 + k^2 + l^2}$. For face-centered rhombohedral crystals $a_0\sqrt{1 + 2\cos^3\beta - 3\cos^2\beta}/\sqrt{(h^2 + k^2 + l^2)\sin^2\beta + 2(hk + hl + kl)(\cos^2\beta - \cos\beta)}$, where β = angle between edges of unit rhombohedron, replaces $a_0/\sqrt{h^2 + k^2 + l^2}$ of the preceding cubic expressions. In cubic crystals $a_0 = (nV_m)^{1/3}$, where n = number of molecules in the elementary crystal unit and $V_m (= M/\rho N_0)$ is the molecular volume, M = molecular weight, ρ = density, N_0 = Avogadro's number = number of molecules per mole. The value of n depends upon the crystal structure. For both rock salt (NaCl) and calcite ($CaCO_3$), $n = 4$. The main sources of error lie in the determination of ρ and N_0.

For calcite, $2d_{100} = [4V_m/\varphi(\beta)]^{1/3}$, where $\varphi(\beta)$ = volume of the calcite rhombohedron which has unit distance between the (100) planes $= (1 + \cos\beta)^2/(\sin\beta)(1 + 2\cos\beta) = 1.0962$, as $\beta = 101°\ 55'$. Compton (6) found $\rho = 2.7116$, corrected to 2.7102 g/cm³, at 20°C, and Compton, Beets, and Defoe (8) also found 2.7102 at 20°C. This value of ρ together with the I. C. T. values for M and N_0 (Vol. I, p. 18 and 43) lead to $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$ cm at 20°C. Other values for ρ are 2.716 (9) and 2.715 (3); the average of these and the preceding two is 2.713 which gives $d_{100} = (3.028 \pm 0.002) \times 10^{-8}$ cm at 20°C.

Some of the better determinations of ρ for rock salt are 2.167 at 17°C (24, 25), 2.15 (9), 2.170 (15), 2.167 (22), 2.174 (19), 2.161 (1) and 2.1632 (13). The mean of these (2.166) gives $d_{100} = (2.814 \pm 0.002) \times 10^{-8}$ cm at 20°C. A more recent determination (14) gives $d_{100} = 2.814[1 + 0.00004(t - 18)] \times 10^{-8}$ cm at t,°C.

GRATING SPACES OF SELECTED CRYSTALS

(c) = measured in terms of calcite, $d_{100} = 3.029$; (r) = measured in terms of rock-salt, $d_{100} = 2.814$. a_0 = length of edge of the unit crystal form; d = grating space, temperature = 20°C. For other data, *see* (2, 20, 23, 26, 29, 30). Unit of a_0 and of d = 1 Å = 10^{-8} cm.

Symbol	Crystal	System	Plane	a_0	d		Lit.
$CaCO_3$.....	Calcite	Rhomb.*	100	6.9347	3.029 ± 0.001		(Calc.)
NaCl.....	Rock salt	Cubic	100	5.628	2.814		(3)
FeS_2.....	Pyrite	Cubic	100 (2)	5.4056	2.703	(c)	(10, 11)
KCl.....	Sylvite	Cubic	100	6.272	3.136	(r)	(31)
KI.....	K iodide	Cubic	100	7.064	3.533	(c)	(5)
$CaSO_4.2H_2O$.	Gypsum	Monoc.*	010		7.584	(r)	(28)
	Mica	Monoc.*	001		10.1	(r)	(4)
$C_{12}H_{22}O_{11}$....	Cane sugar	Monoc.*	100		10.570	(r)	(28)

* Rhomb. = rhombohedral; Monoc. = monoclinic.

Refraction.—If the surface of the crystal is parallel to the reflecting planes in the crystal, if n is the order of the spectrum, and θ is the glancing angle of reflection corresponding to the maximum intensity of radiation of wave-length λ, then $n\lambda = 2d \sin\theta(1 - \delta\cot^2\theta)$, where $1 - \delta$ is the index of refraction of the crystal for radiation of wave-length λ. Measurements of δ for calcite (16) and for pyrites (10, 11) show (10, 11) that $\delta = \frac{e^2}{2\pi m} \times \left[\frac{n_1}{\nu^2 - \nu_1^2} + \frac{n_2}{\nu^2 - \nu_2^2} + \ldots\right]$, where ν = frequency of incident radiation and n_1, n_2, . . . are the numbers of electrons per unit volume having the critical absorption (resonance) frequencies ν_1, ν_2, . . . As ν_1, ν_2, . . . are generally small as compared with ν, a first approximation is $\delta = \frac{e^2}{2\pi m}\left[\frac{n_1 + n_2 + \ldots}{\nu^2}\right]$. For refraction of X-rays, *see* p. 49, and also (7, 12, 17, 18, 21).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Baxter and Wallace, *1*, **38**: 259; 16. (2) Birge, *2*, **14**: 361; 19. (3) Bragg, *5*, **89**: 468; 14. (4) de Broglie, *51*, **4**: 265; 14. (5) Clark and Duane, *197*, **9**: 126, 131; 23. (6) Compton, *2*, **7**: 646; 16. (7) Compton, *3*, **45**: 1121: 23. (8) Compton, Beets and Defoe, *2*, **25**: 625; 25. (9) Dana, *System of mineralogy*, 6th ed., p. 266. New York, Wiley, 1909.

(10) Davis and von Nardroff, *197*, **10**: 60; 24. (11) Davis and von Nardroff, *197*, **11**: 384; 24. (11.1) Davis and Stempel, *2*, **17**: 608; 21. **19**: 504; 22. (12) Davis and Terrill, *197*, **8**: 537; 22. (13) Defoe and Compton, *2*, **25**: 618; 25. (14) Geiss, *3*, **76**: 403; 25. (15) Haigh, *1*, **34**: 1137; 12. (16) Hatley, *2*, **24**: 486; 24. (17) Hatley and Davis, *2*, **23**: 290; 24. (18) Hjalmar, *96*, **15**: 65; 23. (19) Krickmeyer, *7*, **21**: 53; 96.

(20) Ledoux-Lebard and Dauvillier, *34*, **169**: 965; 19. (21) Lorentz, *Theory of electrons and its application to the phenomena of light and radiant heats*. New York, Stechert, 1923. (22) Moseley, *3*, **26**: 1024; 13. (23) Owen, *5*, **94**: 510; 18. (24) Retgers, *7*, **3**: 289; 89. (25) Retgers, *7*, **6**: 193; 90. (26) Siegbahn, *34*, **173**: 1350; 21. (27) Siegbahn, *B78*. (28) Stenstrom, *Diss.*, Lund, 1919. (29) Tutton, *Crystallography and practical crystal measurement*, p. 381. New York, Macmillan, 1911.

(30) Uhler, *2*, **12**: 39; 18. (31) Wagner, *5*, **49**: 625; 16.

ABSORPTION AND SCATTERING OF X-RAYS[1]

J. A. GRAY

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INTRODUCTION

Symbols and Units.—Unless the contrary is stated, the unit of λ and of δλ is 1 Å, and that of each of the other quantities is the appropriate cgse unit. **c, e, h, m_0** have their usual significance (Vol. I, p. 16).

A Atomic weight.
a Area perpendicular to direction of propagation of the radiation.
F Scattering function.
I Intensity of incident radiation; $I = dP/da$.
$I_{s\theta}$ Power of the radiation scattered, per unit solid angle, at angle θ, per unit volume of the scatterer.
$I_{s\theta\alpha}$ Power of the radiation scattered, per unit solid angle, at angle θ, per atom of the scatterer; $I_{s\theta\alpha} = AI_{s\theta}/N_0\rho$.
M Molecular weight.
N_0 Avogadro's constant, molecules per gram-mole.
n_K Number of K-electrons in the atom; similarly for n_L, etc.
P Power carried by the radiation.
R_L^K Discontinuity in photoelectric absorption at K-limit.
R- R-electron = recoil electron.
U- U-electron is an electron that scatters unmodified radiation.
V Difference in potential of terminals of X-ray tube.
v Volume.
Z Atomic number.
α $h\nu/m_0c^2 = 0.0243$ if λ is expressed in Å.
ϵ Extinction coefficient.
η $e^4/m_0^2c^4$.

[1] Covers data prior to October, 1927.

INTRODUCTION

Symboles et unités.—À moins d'une autre indication, l'unité pour λ et pour δλ est 1 Å, et celle pour chaque autre quantité est l'unité cgse appropriée. **c, e, h, m_0** ont leur signification habituelle (Vol. I, p. 16).

A Poids atomique.
a Surface perpendiculaire à la direction de propagation de la radiation.
F Fonction de dispersion.
I Intensité de la radiation incidente; $I = dP/da$.
$I_{s\theta}$ Pouvoir de la radiation dispersée par unité de l'angle solide. à l'angle θ, par unité de volume du corps dispersant.
$I_{s\theta\alpha}$ Pouvoir de la radiation dispersée par unité de l'angle solide, à l'angle θ, par atome du corps dispersant; $I_{s\theta\alpha} = AI_{s\theta}/N_0\rho$.
M Poids moléculaire.
N_0 Constante d'Avogadro, nombre de molécules par Mol. gr.
n_K Nombre d'électrons-K dans l'atome; de même pour n_L, etc.
P Puissance portée par la radiation.
R_L^K Discontinuité dans l'absorption photoélectrique à la limite-K.
R- Electron-R = électron de recul.
U- Electron-U est un électron qui disperse une radiation non modifiée.
V Différence de potentiel entre les extrémités d'un tube à rayons X.
v Volume.
Z Nombre atomique.
α $h\nu/m_0c^2 = 0{,}0243$ si λ est exprimé en Å.
ϵ Coefficient d'extinction.

θ Angle of scattering as measured from direction of propagation of incident radiation.
λ Wave-length.
μ Coefficient of absorption; $\mu = \tau + \sigma$.
μ' Apparent coefficient of absorption, the value found when scattered radiations are not completely eliminated from the transmitted beam.
μ_α Coefficient of atomic absorption; $\mu_\alpha = \mu A/\rho N_0$.
μ_m Coefficient of molecular absorption; $\mu_m = \mu M/\rho N_0$.
μ_e Coefficient of electronic absorption; $\mu_e = \mu A/\rho N_0 Z = \mu_\alpha/Z$.
ν Frequency of incident (ν' = modified) radiation.
ν_c Critical frequency corresponding to an absorption-limit.
ρ Density.
σ Coefficient of scattering; $\sigma = \sigma_s + \sigma_a$.
σ_a Coefficient of true absorption due to scattering.
σ_s Coefficient of true scattering.
$\sigma_\alpha, \sigma_e, \sigma_{a\alpha}, \sigma_{ae}, \sigma_{s\alpha}, \sigma_{se}$ (*See* corresponding notation for μ).
τ Coefficient of photoelectric absorption.
$\tau_\alpha, \tau_m, \tau_e$ (*See* corresponding notation for μ).
ϕ Efficiency of emission of characteristic radiation; ϕ = ratio of number of atoms emitting the radiation to the number from which corresponding photoelectrons are ejected.
φ Angle of ejection of recoil electron, as measured from direction of propagation of incident radiation.
ψ An angle.
ω Solid angle.

EINLEITUNG

Symbole und Einheiten.—Wenn nicht anders bemerkt, ist die Einheit von λ und $\delta\lambda$ 1 Å, und die für jede der anderen Grössen die dazugehörige im cgse System. **c, e, h, m_0** haben deren gewöhuliche Bedeutung)Bd. I, S. 16).
A Atomgewicht.
a Fläche senkrecht zur Fortpflanzungsrichtung der Strahlung.
F Streuungsfunktion.
I Intensität der einfallenden Strahlung; $I = dP/da$.
$I_{s\theta}$ Kraft der gestreuten Strahlung, pro Einheit des festen Winkel, beim Winkel θ, pro Volumeinheit des streuenden Stoffes.
$I_{s\theta\alpha}$ Kraft der gestreuten Strahlung, pro Einheit des festen Winkel, beim Winkel θ, pro Atom des streuenden Stoffes; $I_{s\theta\alpha} = AI_{s\theta}/N_0\rho$.
M Molekulargewicht.
N_0 Avogadro-Konstante, Moleküle pro Gramm-Mol.
n_K Zahl der K-Elektronen pro Atom; in gleicher Weise für n_L, u. s. w.
P Kraft der Strahlung.
R_L^K Diskontinuität der photoelektrischen Absorption an der K-Grenze.
R- R-Elektron = Rückstoss-Elektron.
U- U-Elektronen sind solche, welche unmodifizierte Strahlung streuen.
V Grenzpotentialdifferenz von Röntgen-Röhren.
v Volumen.
Z Atomnummer.
α $h\nu/m_0c^2 = 0{,}0243$ wenn λ in Å ausgedrückt.
ϵ Extinktionskoeffizient.
η $e^4/m_0^2c^4$.
θ Streuungswinkel gemessen an der Richtung der fortschreitenden einfallenden Strahlung.
λ Wellenlänge.

η $e^4/m_0^2c^4$.
θ Angle de dispersion tel qu'il est mesuré à partir de la direction de propagation de la radiation incidente.
λ Longueur d'onde.
μ Coefficient d'absorption; $\mu = \tau + \sigma$.
μ' Coefficient apparent d'absorption; c'est la valeur trouvée lorsque les radiations dispersées ne sont pas complètement éliminées du rayon transmis.
μ_α Coefficient d'absorption atomique; $\mu_\alpha = \mu A/\rho N_0$.
μ_m Coefficient d'absorption moléculaire; $\mu_m = \mu M/\rho N_0$.
μ_e Coefficient d'absorption électronique; $\mu_e = \mu A/\rho N_0 Z = \mu_\alpha/Z$.
ν Fréquence de la radiation incidente (ν' = modifiée).
ν_c Fréquence critique correspondant à une limite d'absorption.
ρ Densité.
σ Coefficient de dispersion; $\sigma = \sigma_s + \sigma_a$.
σ_a Coefficient d'absorption vraie due à la dispersion.
σ_s Coefficient de dispersion vraie.
$\sigma_\alpha, \sigma_e, \sigma_{a\alpha}, \sigma_{ae}, \sigma_{s\alpha}, \sigma_{se}$ (*Voir* la notation correspondante pour μ).
τ Coefficient d'absorption photoélectrique.
$\tau_\alpha, \tau_m, \tau_e$ (*Voir* la notation correspondante pour μ).
ϕ Efficacité de l'émission de la radiation caractéristique; ϕ = rapport du nombre d'atomes émettant la radiation, au nombre de ceux à partir desquels les photoélectrons correspondants sont expulsés.
φ Angle d'éjection de l'électron de recul, tel qu'il est mesuré à partir de la direction de propagation de la radiation incidente.
ψ Un angle.
ω Angle solide.

INTRODUZIONE

Simboli e unità.—A meno che non venga altrimenti indicato le unità di λ e di $\delta\lambda$ è 1 Å e quello di ogni altra quantità sono le unità appropriate del sistema cgse. **c, e, h, m_0** hanno il loro consueto significato (Vol. I, p. 16).
A Peso atomico.
a Area perpendicolare alla direzione di propagazione della radiazione.
F Funzione di dispersione.
I Intensità della radiazione incidente; $I = dP/da$.
$I_{s\theta}$ Potenza della radiazione dispersa, per unità di angolo solido, a un angolo θ, per unità di volume del mezzo dispersore.
$I_{s\theta\alpha}$ Potenza della radiazione dispersa, per unità di angolo solido, a un angolo θ, per atomo del mezzo dispersore; $I_{s\theta\alpha} = AI_{s\theta}/N_0\rho$.
M Peso molecolare.
N_0 Costante di Avogadro, molecole per grammimolecola.
n_K Numero di elettroni K nell'atomo; similmente per n_L, ecc.
P Potenza portata dalla radiazione.
R_L^K Discontinuità nell'assorbimento fotoelettrico al limite K.
R- R-elettrone = elettrone di rimbalzo.
U- U-elettrone è un elettrone che disperde la radiazione immodificata.
V Differenza di potenziale ai termini del tubo a raggi X.
v Volume.
Z Numero atomico.
α $h\nu/m_0c^2 = 0{,}0243$ se λ è espressa in Å.
ϵ Coefficiente di estinsione.
η $e^4/m_0^2c^4$.
θ Angolo di dispersione come viene misurato dalla direzione di propagazione della radiazione incidente.
λ Lunghezza d'onda.
μ Coefficiente di assorbimento; $\mu = \tau + \sigma$.
μ' Coefficiente apparente di assorbimento; il valore trovato

μ Absorptionskoeffizient; $\mu = \tau + \sigma$.
μ' Scheinbarer Absorptionskoeffizient, der Wert, der sich ergibt, wenn die gestreute Strahlung nicht vollständig frei vom durchdringenden Strahl ist.
μ_α Koeffizient der Atom-Absorption; $\mu_\alpha = \mu A/\rho N_0$.
μ_m Koeffizient der Molekularabsorption; $\mu_m = \mu M/\rho N_0$.
μ_e Koeffizient der Elektronen Absorption; $\mu_e = \mu A/\rho N_0 Z = \mu_\alpha/Z$.
ν Frequenz der einfallenden Strahlung (ν' = modifiziert).
ν_c Kritische Frequenz entsprechend einer Absorptionsgrenze.
ρ Dichte.
σ Streuungskoeffizient; $\sigma = \sigma_s + \sigma_a$.
σ_a Koeffizient der wahren Absorption durch Streuung.
σ_s Koeffizient der wahren Streuung.
σ_α, σ_e, $\sigma_{a\alpha}$, σ_{ae}, $\sigma_{s\alpha}$, σ_{se} (*Siehe* die entsprechenden Bemerkungen für μ).
τ Koeffizient der photoelektrischen Absorption.
τ_α, τ_m, τ_e (*Siehe* die entsprechende Bemerkungen für μ).
ϕ Leistung der Emission charakteristischer Strahlung; ϕ = Verhältnis der Anzahl der Strahlung aussendenden Atome zu der Anzahl von welchen entsprechende photoelektrische Elektronen abgestossen werden.
φ Winkel unter welchem Rückstosselektronen abgestossen werden, gemessen von der Richtung des Fortschreitens der einfallenden Strahlung.
ψ Winkel.
ω Fester Winkel.

quando le radiazioni disperse non sono completamente eliminate dal fascio trasmesso.
μ_α Coefficiente di assorbimento atomico; $\mu_\alpha = \mu A/\rho N_0$.
μ_m Coefficiente di assorbimento molecolare; $\mu_m = \mu M/\rho N_0$.
μ_e Coefficiente di assorbimento elettronico; $\mu_e = \mu A/\rho N_0 Z = \mu_\alpha/Z$.
ν Frequenza della radiazione incidente (ν' = modificata).
ν_c Frequenza critica corrispondente ad un assorbimento limite.
ρ Densità.
σ Coefficiente di dispersione; $\sigma = \sigma_s + \sigma_a$.
σ_a Coefficiente di assorbimento vero dovuto a dispersione.
σ_s Coefficiente di dispersione vero.
σ_α, σ_e, $\sigma_{a\alpha}$, σ_{ae}, $\sigma_{s\alpha}$, σ_{se} (*Vedi* la notazione corrispondente per μ).
τ Coefficiente di assorbimento fotoelettrico.
τ_α, τ_m, τ_e (*Vedi* la corrispondente notazione per μ).
ϕ Efficienza dell'emissione della radiazione caratteristica; ϕ = rapporto fra il numero di atomi che emettono la radiazione e il numero di quelli dai quali vengono emessi fotoelettroni.
φ Angolo di eiezione dell'elettrone di rimbalzo, quale viene misurato dalla direzione di propagazione della radiazione incidente.
ψ Un angolo.
ω Un angolo solido.

Restriction.—Unless the opposite is explicitly stated (Tables 11, 12, 13), it is assumed, throughout this report, that in determining absorption coefficients, the measuring instrument is so far from the absorbing material and is so screened that it indicates merely the intensity of the radiant energy which is traveling in the direction of the primary beam. It is the absorption, as so measured, that is considered, and to which the coefficients of absorption refer.

Obviously the amount of radiation reaching a given region within the absorbing material cannot be computed directly from this absorption, for that region receives scattered and characteristic radiations from all the surrounding material, traveling in every direction. This extra radiation may be several times as great as that incident in the direction of the primary beam, and it is only the latter that can be computed directly from the coefficient of absorption. This difference is of much importance in the use of X-rays for therapeutic purposes, and has been studied by many *cf.* (**141, 231**).

Absorption and Scattering.—When a beam of X-rays passes through an atomic system, it may be altered by the action of the non-nuclear electrons. The following three types of action are recognized, though types (*b*) and (*c*) are parts of the same general phenomenon.

(*a*) *Photoelectric Effect.*—An electron is dislodged from its energy-level, and absorbs all the energy $\mathbf{h}\nu$ of the impinging quantum. Such electrons are called photoelectrons, and are emitted with the energy $\mathbf{h}\ (\nu - \nu_c)$, where ν_c is the frequency characteristic of the level from which they come. They may be described as primary photoelectrons. The vacancy caused by the removal of a photoelectron is soon refilled by an electron from a lower energy-level having a characteristic frequency $\nu_{c'}$. Accompanying this, there may be an emission of characteristic radiation which, on an average, is uniform in all directions, and has a frequency $(\nu_c - \nu_{c'})$ and energy $\mathbf{h}(\nu_c - \nu_{c'})$. This is the simple photoelectric effect.

From some of the atoms this characteristic radiation is not emitted, but additional electrons, which may be called secondary photoelectrons, are emitted. This is the compound photoelectric effect. The characteristic radiation may be regarded as being absorbed in the atom and causing the ejection of photoelectrons from other levels, with energies $\mathbf{h}(\nu_c - \nu_{c'})$, $\mathbf{h}(\nu_{c'} - \nu_{c''})$, etc.

(*b*) *Scattering without Change of Frequency.*—An electron, though not dislodged from its energy-level, may cause a scattering of the primary radiation. This scattered radiation has the same frequency as the primary, and is called the unmodified scattered radiation. Such electrons may be called *U*-electrons. They scatter the radiation coherently.

(*c*) *Scattering with Change of Frequency.*—An electron may be dislodged from its energy-level without absorbing more than a fraction, $(\nu - \nu')/\nu$, of the energy of the impinging quantum. Such an electron is called a "recoil" (or an *R*-) electron. It leaves the atom with energy $\mathbf{h}(\nu - \nu' - \nu_c)$, radiation of frequency ν', differing from ν, is scattered, and characteristic radiation of frequency $(\nu_c - \nu_{c'})$ is emitted as the vacancy is refilled by an electron from the level $\nu_{c'}$. This scattered radiation is known as the modified scattered radiation. It is not scattered coherently.

Extinction.—Darwin (**123, 124**) has shown that when a crystal is set so as to reflect the incident rays, the effective absorption should be greater than the true. This phenomenon is due to what is called extinction and has been observed, *cf.* (**20, 58, 60, 63, 220**); *see* Table 5, NaCl. For a perfect crystal, extinction occurs only when the orientation is such as to reflect the incident beam, and arises from the fact that beams which have been twice reflected are parallel to and exactly opposite in phase to the primary beam. This is called primary extinction. An imperfect crystal may be regarded as a mosaic of small perfect crystals with various orientations. Whatever the orientation of the mosaic there will be extinction as the result of reflection by those individual crystals that are then in the proper position. This extinction is called secondary extinction; the range of orientation over which it occurs increases with the degree of the imperfection of the crystal.

Efficiency of Emission of Characteristic Radiation.—Owing to the existence of the compound photoelectric effect, the number (n_τ) of atoms that emit a certain characteristic radiation is less

than that (n_e) of those that emit primary photoelectrons from the corresponding level. The ratio $\phi = n_\tau/n_e$ may be called the efficiency of the emission of this radiation (*see* Table 1).

TABLE 1.—EFFICIENCY OF EMISSION OF *K*-RADIATION

ϕ_K = ratio of number of atoms that emit *K*-radiation to the number from which an electron is ejected from the *K*-level; Z = atomic number of the radiator. ϕ_K is approximately independent of λ; $\phi_K > \phi_L$.

Z	$\phi_K(R_L^K - 1)/R_K$			
	(227, 240)	(52)	(21)	(240)
18	0.07*			
24	0.23			
26	0.32	0.25	0.33	0.29
27	0.39	0.25		
28		0.25	0.39	0.35
29	0.42	0.25	0.44	0.40
30	0.51		0.50	0.46
34				0.59
35		0.50		0.59
36	0.51*			
42			0.83	
47		0.93	0.75	
53				0.75
54	0.70*			

*From(13).

Definitions (*see also* preceding sections).—*Intensity of a Beam of Radiation.*—By definition, the intensity (I, I_0, I_x) at any point of a beam of radiation is the power (P) delivered at that point per unit of area (a) normal to the direction of propagation of the beam; $I = dP/da$.

Coefficients of Absorption.—If the incident beam consists of parallel rays of a single wave-length (λ) and has initially the intensity I_0, its intensity (I_x) after passing through a thickness x is $I_x = I_0 e^{-\mu x}$, where μ is a constant called the coefficient of absorption; μ depends upon λ, and is characteristic of the material. As $I = dP/da$, and the amount of material (dm) involved in the decrease of dP when the radiation advances from 0 to x is that contained in the volume $x\,da$, it follows that the decrease in I may be expressed in terms of dm/da; *i.e.*, in terms of the amount of material per unit of area, that is traversed by the radiation in going the distance x. The value of dm may be expressed in terms of any appropriate quantity, such as volume, mass, number of atoms, number (Z) of non-nuclear electrons, number of molecules; the corresponding values of dm/da are x, ρx, $\rho N_0 x/A$, $\rho N_0 Z x/A$, $\rho N_0 x/M$, and of the absorption coefficient are μ, μ/ρ, $\mu A/\rho N_0 \equiv \mu_\alpha$, $\mu A/\rho N_0 Z \equiv \mu_e$, $\mu M/\rho N_0 \equiv \mu_m$, which are called the coefficientof absorption, of mass absorption, of atomic absorption, of electronic absorption, and of molecular absorption, respectively.

The part of μ that is due to the photoelectric effect is denoted by τ (the coefficient of fluorescent or of photoelectric absorption), and that due to scattering, by σ (the coefficient of scattering); $\mu = \tau + \sigma$. In the scattering process, part of the power lost by the primary beam reappears as scattered radiation, the rest is absorbed by recoil electrons. The part of σ that is due to the former is denoted by σ_s (the coefficient of true scattering), that due to the latter, by σ_a (the coefficient of true absorption due to scattering); $\sigma = \sigma_s + \sigma_a$.

Effective Wave-length.—It has become customary, especially in the therapeutic use of X-rays, to speak of the effective wave-length of a beam of heterogeneous radiation. Duane (141) defines it as the wave-length of that beam of homogeneous radiation which, on passing through 0.5 mm of copper, is reduced in intensity by the same fractional amount as the heterogeneous beam would be, under the same conditions. It might also be defined as the wave-length of that beam of homogeneous radiation which would be reduced to half its intensity on passing through such a thickness of copper as will produce the same reduction in the heterogeneous beam. Allen (6) deduces an effective wave-length of strongly filtered "end" radiation from the equation $(\mu/\rho)_{Al} = 14\lambda^{2.92}$, where $(\mu/\rho)_{Al}$ refers to the absorption of such "end" radiation in Al, and 2 Å $< \lambda <$ 4 Å. This gives too small a value for λ.

In no case does the effective wave-length alone define the characteristics of the beam; it must always be considered in connection with the source and previous filtering of the beam. The more heterogeneous the beam, the less significant is the term "effective wave-length."

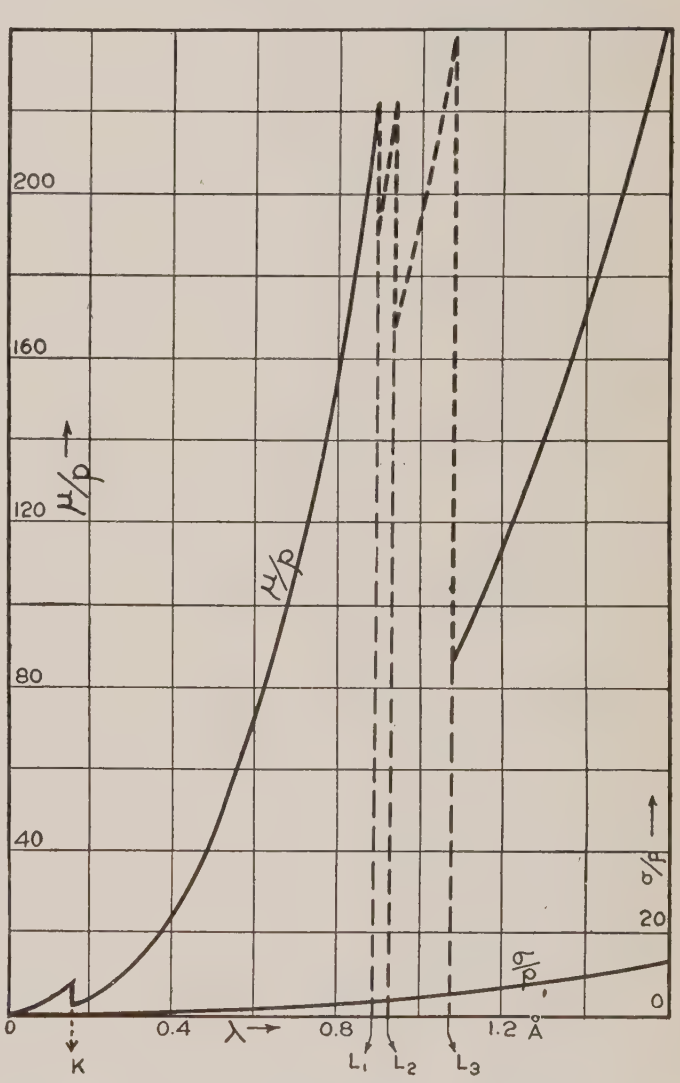

FIG. 1.—Coefficients of absorption and scattering of Pt: variation with wave-length (λ). Unit of μ/ρ and σ/ρ = 1 cm²/g. *K*, L_{11}, L_{21}, L_{22} indicate the positions of the corresponding absorption-limits.

The views expressed above are not in agreement with those of experimenters who have observed the *J*-phenomena (*cf.* p. 1). Internal absorption of γ-rays is not dealt with here.

ABSORPTION

For apparent absorption of γ-rays, *see* p. 20

A magnetic field produces no effect upon the absorption (41, 42, 100, 330). An increase in temperature has a small effect, the sign depending upon the wave-length (261). Unless λ is small, σ is very much smaller than τ, and its variation with λ is negligible as compared with that of τ (*cf.* p. 16). This will be the case for many of the data that will be considered.

The coefficient of mass absorption of a mixture can be computed by means of the simple additive relation $m(\mu/\rho) = m_1 \times (\mu/\rho)_1 + m_2(\mu/\rho)_2 + \ldots$, where m, m_1, m_2, . . . are the masses of the mixture and its several components; $m = m_1 + m_2 + \ldots$

The coefficient of molecular absorption ($\mu_m = \mu M/\rho N_0$) of many compounds can be similarly computed from the atomic absorptions of their constituent atoms (*v.* (16–19, 250, 317, 343)): $\mu_m = n_1(\mu_\alpha)_1 + n_2(\mu_\alpha)_2 + \ldots$, where $M = n_1A_1 + n_2A_2 + \ldots$ This expression for μ_m is not universally correct; *v.* (16–19, 245); for example, for values of λ between 40 and 80 Å, Holweck (193, 194) found μ/ρ to be the same for celluloid as for hydrogen.

Variation with Wave-length and Absorber.—For any given material the variation of μ with λ exhibits certain discontinuities (*see* Fig. 1); the values of λ at which they occur are called the absorption limits of the material, and each has been found to be the longest wave-length capable of exciting a certain X-ray series characteristic of the material (*cf.* p. 23). The discontinuities are not absolutely sharp, but the entire change occurs within a very narrow range of wave-lengths (0.01 Å) (326); *cf.*, *however* (268, 271).

When λ is kept constant and absorbers having various values of Z are used, similar discontinuities appear in the variation of μ with Z, each occurring as Z passes from a value for which the absorption limit is greater, to one for which it is smaller, than λ.

The ratio of the maximum to the minimum value of τ at any group of discontinuities may be called the value of the discontinuity at that limit. It is not known accurately, partly owing to the difficulty of measuring μ and partly to our ignorance of the values of σ. At the K-limit the value of the discontinuity, which may be signified by R_L^K, (*v.* (269)), is of the same order as λ_L/λ_K, where λ_K, λ_L are the wave-lengths of the K- and of the shortest (L_{11}) of the L-absorption limits.

TABLE 2.—VALUES OF THE τ-DISCONTINUITY (R_L^K) AT THE K-LIMIT
Unit of λ = 1 Å = 10^{-8} cm

Absorber	λ_K	$\lambda_{L_{11}}$	λ_L/λ_K	R_L^K	Lit.
26Fe	1.738	14.6	8.4	9.5	(6)
28Ni	1.489	12.1	8.1	9.0	(6)
29Cu	1.379	11.0	8.0	9.1	(6)
30Zn	1.296	10.2	7.9	8.8	(6)
42Mo	0.618	4.30	7.0	7.3	(6)
				7.5	(269)
46Pd	0.506	3.42	6.8	6.8	(315)
47Ag	0.485	3.26	6.7	7.3	(6)
				7.8	(269)
				6.7	(315)
50Sn	0.424	2.77	6.5	6.9	(6)
				6.6	(269)
				6.1	(315)
74W	0.178	1.024	5.8	6.2	(6)
				5.55	(269)
78Pt	0.158	0.892	5.6	6.0	(6)
79Au	0.152	0.861	5.6	5.8	(6)
				5.65	(269)
82Pb	0.139	0.780	5.6	5.0	(6)
				5.4	(269)

Between adjacent absorption limits, μ and τ vary continuously with λ (*cf.* Table 5). None of the theoretical formulae express this relation satisfactorily. De Broglie's formula (70), which may be put in the form

$$\tau_\alpha = \frac{\pi e^2}{m_0 c^2}\lambda^3\left\{\frac{n_K}{\lambda_K^2} + \frac{n_L}{\lambda_L^2} + \ldots\right\} \times 10^{-8}$$

gives, for $\lambda < \lambda_K$, $\tau_\alpha(\text{Cu}) = 9.9\lambda^3(10)^{-21}$ and $\tau_\alpha(\text{Bi}) = 1.1\lambda^3(10)^{-18}$, the approximate experimental values being $1.5\lambda^3(10)^{-20}$ and $1.0 \times \lambda^3(10)^{-18}$. It also gives R_L^K a value that is twice as great as the one observed (269). Formulae, differing from de Broglie's by a numerical factor only, have been obtained by Thomson (319) and Compton (104). From Kramer's (230) formula

$$\tau_\alpha = \frac{64\pi^4}{3\sqrt{3}} \cdot \frac{e^{10}m_0}{c^4h^6}\left(\frac{n_K}{1.2} + \frac{n_L}{2^4 \cdot 3} + \frac{n_m}{3^4 \cdot 4} + \ldots\right) Z^4\lambda^3(10)^{-24}$$

we get $\tau_\alpha = 1.2\lambda^3Z^4(10)^{-26}$, if $\lambda < \lambda_K$, and $R_L^K = 5\,5$; the value of τ_α is about 40 % too low. By applying the methods of Schrödinger's wave mechanics, Wentzel (331) has obtained for the absorption due to the K-electrons the expression

$$\tau_\alpha = \frac{32}{3} \cdot \frac{e^2}{m_0c^2}\left(\frac{\lambda}{\lambda_K}\right)^{5/2}\left\{3\sqrt{\lambda}\cos\psi + \sqrt{\lambda_K}\sin\psi\right\}^2(10)^{-8}$$

where ψ is an undetermined phase angle, which may depend on λ and Z.

Several empirical formulae have been deduced, mostly of the form $\tau_\alpha = CZ^m\lambda^n(10)^{-26}$, where m and n are approximately equal to 4 and 3, respectively, and C changes as λ passes through an absorption limit. No values yet proposed for C, m, and n are entirely satisfactory, especially when $\lambda < 0.1$ Å; those most used are given in Table 3, m being taken as 4. The best are those given by Gray, but those by Richtmyer and Richtmyer and Warburton are the most generally accepted, although derived from a small range of observations.

TABLE 3.—VALUES OF C AND n IN $\tau_\alpha = CZ^4\lambda^n(10)^{-26}$
Unit of λ = 1 A = 10^{-8} cm

Range	$\lambda < \lambda_K$		$\lambda_K < \lambda < \lambda_{L_{11}}$		$\lambda_{L_{22}} < \lambda < \lambda_{M_{11}}$		Lit.
Author	C	n	C	n	C	n	
R. and W.*.....	2.24	3	0.33	3			(266, 272)
Allen.....	2.18	2.92	0.299	2.92			(5)
Gray.....	1.92P†	3	0.255	2.7	0.058	2.6	(175)

* Richtmyer and Warburton.

† $P = (1 + 0.008Z)\left\{1 - \frac{\lambda}{4\lambda_K} - \frac{\lambda}{50\lambda_K^2}\right\}$, λ and λ_K being expressed in Ångstroms.

Jönsson (*Diss.*, Upsala, 1928) has shown that, to a high degree of approximation

$$\tau/\rho = \frac{Z}{A} \cdot \frac{\lambda_K}{\lambda_c} \cdot f(Z\lambda)$$

for values of $Z\lambda > 8$ and $\lambda < 12$ Å. λ_c is the nearest critical absorption wave-length $> \lambda$. Jönsson tabulates values of the function $f(Z\lambda)$. We may write $f(Z\lambda) = (Z\lambda)^x$ where $x = 2.03 - 10/Z\lambda + 100/Z^3\lambda^3$. This formula and the first of Gray's may be used to give an approximate check on experimental results and to deduce unknown values of τ/ρ. Jönsson's generalization is not true for values of $Z\lambda < 8$ nor for a light element such as carbon.

TABLE 4.—COEFFICIENTS OF ABSORPTION FOR λ = 0.586, 0.631 AND 0.709 Å

All substances for which either μ/ρ or μ_m is given in this section are here listed, with references to all sources utilized in determining any of these values; references to other data are placed after "*cf.*" For certain substances, values of μ/ρ or of μ_m are given for no other λ; no additional data for absorption at these λ's are given elsewhere in this section. Substances are listed in the order: Elements, inorganic compounds, organic compounds. Italics indicate the value of μ/ρ that next precedes a known absorption-limit. $Q = (Z/29)^4$, 29 is Z for Cu (*cf.* Table 3); $\mu_m = \mu M/\rho N_0 \equiv (k\mu/\rho) \times 10^{-23}$, where M = molecular weight as

indicated by the formula, $N_0 = 6.061 \times 10^{23}$ molecule per g-mole. Unit of $\lambda = 1$ Å $= 10^{-8}$ cm; of $\mu/\rho = 1$ cm^2/g; of $\mu_m = 10^{-23}$ cm^2 per molecule; of $k = 10^{-23}$ g per molecule.

λ			0.586	0.631	0.709	Lit.
(1)	Q	k	μ/ρ			
Ag47	6.91	17.80	15.5	19.4	26.2	(4, 5, 6, 266, 269, 315); cf. (1, 65, 215, 255, 343)
Al13	0.040	4.45	3.00	3.70	5.21	(4, 5, 6, 239, 266); cf. (1, 65, 144, 177, 189, 197, 215, 255, 256, 315, 317, 343)
Au79	55.1	32.54	75.0		122	(4, 5, 6, 269); cf. (65, 215, 343)
Ba56	13.91	22.67	26.3		41.3	(5); cf. (343)
Bi83	67.1	34.48	*See* Table 5			(5); cf. (1)
Br35	2.12	13.19	45.3		67.2	(343); cf. (301)
C6	0.0018	1.980	0.450* 0.382†	0.550* 0.435†	0.630* 0.550†	(4, 5, 6, 189); cf. (1, 215, 250, 301, 317, 343)
Ca20	0.23	6.61	10.9		19.7	(343)
Cd48‡	7.51	18.55	17.5		30.3	(343)
Cl17	0.12	5.85	6.9		11.9	(343); cf. (301)
Co27	0.75	9.73	22.6		38.1	(272, 343)
Cr24	0.47	8.58	18.1		29.6	(343)
Cu29	1.00	10.49	29.0	36.7	51.0	(4, 5, 6, 239, 266, 272, 315); cf. (1, 65, 144, 177, 197, 215, 337, 343)
Fe26	0.65	9.21	23.1	27.9	37.6	(4, 5, 6, 239, 272); cf. (1, 65, 189, 198, 215, 343)
H1§	1.4×10^{-8}	0.1663	0.381	0.388	0.401	(17, 250, 297); cf. (1)
I53	11.15	20.94	22.8		39.4	(343); cf. (301)
K19	0.18	6.45	9.1		16.1	(343)
Li3	11×10^{-5}	1.145	0.300	0.360		(189)
Mg12	0.029	4.01			4.1	(4); cf. (215, 256, 343)
Mn25	0.55	9.06	19.2		34.4	(343)
Mo42	4.40	15.84	75.0	13.8	19.5	(266, 269); cf. (315, 343)
N7	0.0034	2.31			1.1	(189); cf. (193, 194, 343)
Na11	0.021	3.80	2.09		3.40	(343)
Ni28	0.87	9.68	28.9	34.8	45	(4, 5, 6, 239, 272); cf. (65, 215, 260, 343)
O8	0.058	2.64	0.71	0.850	1.13	(189); cf. (1, 193, 194, 250, 301, 317, 343)
Pb82	63.9	34.19	74.5	101	140	(4, 5, 6, 269); cf. (1, 65, 177, 197, 198, 256, 343)

* (5).
† (189); values agree with those obtained from liquids; *cf.* (250).
‡ For Cd, $\mu/\rho = 5.48$ for $\lambda = 0.188$.
§ Values of μ/ρ are computed, *see* Table 5.

λ			0.586	0.631	0.709	Lit.
(1)	Q	k	μ/ρ			
Pd46	6.33	17.60		17.2	23.8	(315); cf. (65)
Pt78	52.3	32.21	73.5	87.0	117	(4, 5, 6); cf. (1, 65, 215, 343)
Rh45‖	5.80	16.98	15.2			(322, 343)
S16	0.093	5.29	5.90	6.90	9.80	(4, 5); cf. (301, 343)
Sn50	8.84	19.59	18.7	22.6	32.1	(4, 5, 6, 269); cf. (1, 65, 177, 215, 256, 343)
Sr38	2.95	14.46	57.7		94.3	(343)
Th90	92.8	38.30	*See* Table 5			(5); cf. (1)
U92	101	39.30		88	*121*	(5); cf. (1, 315)
W74	42.4	30.36	56.8	*75.0*		(5, 269); cf. (343)
Yt39	3.27	14.68	60.3		99.9	(343)
Zn30	1.15	10.79	34.3	43.0	59.0	(5, 6); cf. (1, 65, 177, 215, 256, 343)
Zr40	3.62	15.02			19.7	(343)

λ			0.586		0.709		Lit.
Substance	k		μ_m	μ/ρ	μ_m	μ/ρ	
Air			*See* Table 5				(215); cf. (165)
H_2O	2.972		2.04	0.686	3.21	1.08	(189, 250, 266); cf. (317, 343)
HCl	6.017		40.8	6.77	70.95	11.8	(343)
SO_2	10.57		*See* Table 5				(215); cf. (165)
H_2SO_4	16.18		39.3	2.43	56.43	3.48	(343)
N_2H_4	5.188		*See* Table 5				(19, 20)
NH_4NO_3	13.21				13.53	1.02	(343)
H_3PO_4	16.18		32.7	2.02	53.46	3.34	(343)
CO_2	7.26		*See* Table 5				(215); cf. (165)
$Zr(SO_4)_2$	46.72				407.7	8.73	(343)
$Pb(NO_3)_2$	54.65		2563.0	46.9	3496.4	64.0	(343)
$ZnCl_2$	22.49		448.9	19.5	729.3	32.34	(343)
$ZnSO_4$	26.64		404.9	15.2	656.6	24.6	(343)
$CdCl_2$	30.25		404.8	13.3	701.2	23.2	(343)
$CuCl_2$	22.19		386.4	17.4	630.0	28.4	(343)
$CuSO_4$	26.34		339.7	12.9	542.2	20.5	(343)
$AgNO_3$	28.03		299.7	10.6	558.6	19.9	(343)
$MnCl_2$	20.76		255.4	12.3	451.7	21.7	(343)
$FeCl_2$	26.76		325.5	12.2	556.2	20.8	(343)
$CoCl_2$	21.43		302.2	14.1	507.4	23.7	(343)
$NiCl_2$	21.39		325.0	15.2	603.4	28.2	(343)
$CrCl_3.4H_2O$	38.02		284.4	7.48	474.5	12.5	(343)
$(NH_4)_2MoO_4$	32.35				341.3	10.6	(343)
U_3O_8	139.0		*See* Table 5				(315)
$Yt(NO_3)_3$	45.38		898.5	19.8	1492.7	32.9	(315)
$MgCl_2$	15.72				155.4	9.89	(343)
$CaCl_2$	18.31		152.7	8.34	270.3	14.7	(343)
$SrCl_2$	26.16		935.1	35.7	1503.5	57.5	(343)
$Sr(NO_3)_2$	34.92		844.6	24.3	1380.0	39.5	(343)
$BaCl_2$	34.37		677.0	19.7	1074.7	31.3	(343)
NaOH	6.60				15.51	2.35	(343)
NaCl	9.64		48.43	5.01	76.10	7.89	(343)
NaBr	16.98		605.2	35.6	899.2	53.0	(343)
NaI	24.74		485.4	19.6	838.5	34.3	(343)
Na_3RhCl_6	63.47		522.4	8.24			(343)
Na_2MoO_4	30.21		1158	38.3			(343)
Na_2WO_4	48.51		1747.0	36.0			(343)
KCl	12.30		99.4	8.08	173.4	14.1	(343)
Mica			*See* Table 5				(322)

Formula	Substance (λ = 0.709)	k	μ_m	μ/ρ	Lit.
CH_3I	Methyl iodide	23.42	*See* Table 5		(215); cf. (165)
$C_2H_4O_2$	Methyl formate	7.27	*See* Table 5		(19, 20)
C_2H_5Br	Ethyl bromide	17.98	*See* Table 5		(215); cf. (165)
C_3H_6O	Acetone	9.58	6.62	0.691	(317)

‖ For Rh, $\mu/\rho = 14.2$, 15.1, 17.7 if $\lambda = 0.545$, 0.586, 0.612, respectively.

TABLE 4.—(*Continued*)

Formula	Substance (λ = 0.709)	k	μ_m	μ/ρ	Lit.
C_3H_6O	Acetone	9.58	7.54	0.787	(343)
C_3H_6O	Allyl alcohol	9.58	*See* Table 5		(19, 20)
$C_3H_6O_2$	Ethyl formate	12.22	9.70	0.794	(317)
$C_3H_6O_2$	Propionic acid	12.22	10.2	0.833	(343)
$C_3H_6O_2$	Propionic acid	12.22	*See* Table 5		(19, 20)
$C_3H_6O_3$	Dimethyl carbonate	14.86	*See* Table 5		(19, 20)
C_3H_8O	Isopropyl alcohol	9.91	6.84	0.690	(317)
$C_3H_8O_2$	Trimethyleneglycol	12.55	9.86	0.786	(317)
C_4H_8O	Methyl ethyl ketone	11.89	*See* Table 5		(19, 20)
$C_4H_8O_2$	Ethyl acetate	14.53	11.55	0.795	(317)
$C_4H_8O_2$	Ethyl acetate	14.53	*See* Table 5		(19, 20)
$C_4H_8O_2$	Methyl propionate	14.53	11.44	0.787	(317)
C_6H_6	Benzene	12.88	7.07	0.549	(317)
C_6H_6	Benzene	12.88	6.93	0.538	(250); *cf.* (317)
$C_6H_{12}O$	Cyclohexanol	16.52	10.5	0.634	(250)
$C_6H_{12}O_3$	Paraldehyde	21.80	17.3	0.794	(343)
$C_6H_{12}O_3$	Paraldehyde	21.80	*See* Table 5		(19, 20)
C_7H_8	Toluene	15.19	8.35	0.550	(317)
C_7H_8	Toluene	15.19	8.13	0.535	(250); *cf.* (317)
C_7H_8	Toluene	15.19	*See* Table 5		(19, 20)
C_7H_8O	Benzyl alcohol	17.83	*See* Table 5		(19, 20)
C_7H_{16}	*n*-Heptane	16.52	8.77	0.531	(250)
C_8H_{10}	*n*-Xylene	17.50	9.40	0.537	(250)
C_8H_{18}	Octane	18.83	*See* Table 5		(19, 20)
$C_8H_{18}O$	Octyl alcohol	21.47	*See* Table 5		(19, 20)
C_9H_{12}	Mesitylene	19.82	10.6	0.534	(250)
$C_{10}H_{16}$	Limonene	22.46	12.06	0.537	(317)
$C_{10}H_{16}$	Pinene	22.46	12.08	0.538	(317)
	Celluloid		*See* Table 5		(244); *cf.* (193, 194)
	Gelatin		*See* Table 5		(205)

TABLE 5.—COEFFICIENTS OF ABSORPTION OF X-RAYS AND γ-RAYS

For apparent coefficients of absorption of γ-rays, *see* Tables 12, 13, 14; for coefficients of absorption by those substances for which there are no data except for λ = 0.586, 0.631, or 0.709 Å, *see* Table 4.

The data in this table are believed to be the best available; many of them are averages of graphical values given in the sources listed in Table 4; all are founded on experimental values. Owing to frequent wide variations in the values obtained by different observers, it is difficult to make a useful estimate of the accuracy of the data. For wave-lengths greater than 2 Å, strongly filtered "end" radiations have been used. As the tabulated value of λ is the effective λ defined by Allen's equation $(\mu/\rho)_{Al} = 14\,\lambda^{2.92}$, it is too small; the corresponding values of μ/ρ are not accurate when this effective λ is near an absorption limit. In fact, all the given values of μ/ρ for wave-lengths near the L and M absorption-limits are liable to be inaccurate. For additional data for λ > 2 Å, *see* (193, 194, 233). In general, *see* Table 4 for literature references.

Italics indicate the value of μ/ρ that next precedes a known absorption-limit. Substances are listed in the order: Elements, inorganic compounds, organic compounds; and the first is divided into the sections: γ-rays, λ = 0.08 to 0.11 Å, λ = 0.1 to 1.0 Å, λ = 1.0 to 3.9 Å, and radiation specified solely by the tube voltage. The symbol of an element is followed by its atomic number (Z); $Q = (Z/29)^4$, 29 is Z for Cu (*cf.* Table 3); $\mu_\alpha = \mu A/\rho N_0 = (k\mu/\rho) \times 10^{-23}$, $\mu_m = \mu M/\rho N_0 = (k\mu/\rho) \times 10^{-23}$, where A = atomic weight, M = molecular weight as indicated by the formula, $N_0 = 6.061 \times 10^{23}$ molecule per g-mole; V = potential difference of terminals of the tube. Unit of λ = 1 Å = 10^{-8} cm; of μ/ρ = 1 cm²/g; of $\mu_m = 10^{-23}$ cm² per molecule; of $k = 10^{-23}$ g per molecule; of V = 1000 volt.

I. γ-rays of Ra(B and C) filtered through x cm of Pb*

Symbol	Al13	Cu29	Fe26	Mg12	Pb82	Sn50	Zn30	
Q	0.040	1.00	0.65	0.029	63.9	8.84	1.15	
k	4.45	10.49	9.21	4.01	34.19	19.59	10.79	
x	μ/ρ							Lit.
5.35		0.0450			0.0480			(177)
4.30		0.0452			0.0487			(177)
3.25		0.0460			0.0513			(177)
2.2	0.0559			0.0566	0.0633	0.0525	0.0567	(256)
2.2	0.0486	0.0479			0.0552	0.0448	0.0466	(177)
1.5			0.0632		0.0727			(198)
1.0	0.0514				0.0626	0.0498		(353)
1.0		0.0510			0.0630			(177)
0.3	0.0560				0.0830			(177)

*For further data on γ-rays, *see* (1, 2).

II. X-rays

λ			0.081	0.085	0.090	0.095	0.100	0.110
(1)	Q	k	μ/ρ					
Ag47	6.91	17.8	0.740	0.830	0.900	1.02	1.12	1.32
Al13	0.040	4.45	0.145	0.153	0.160	0.165	0.167	0.171
Au79	55.1	32.54	2.44	2.65	2.85	3.30	3.60	4.28
Bi83	67.1	34.48	2.25	2.76	3.00	3.45	3.75	4.50
C6	0.0018	1.98	0.143	0.145	0.148		0.150	
Cu29	1.00	10.49	0.270		0.295		0.335	0.390
Fe26	0.65	9.21	0.235		0.252		0.285	0.325
Ni28	0.87	9.68	0.265		0.290		0.340	0.385
Pb82	63.9	34.19	2.53	2.78	3.00	3.46	3.77	4.46
Pt78	52.3	32.21	2.50	2.75	2.95	3.38	3.65	4.35
S16	0.093	5.29	0.155	0.170	0.182	0.186	0.190	0.195
Sn50	8.84	19.59	0.80	0.88	0.95		1.16	1.45
U92	101	39.30				*3.53*		
W74	42.4	30.36	2.40	2.60	2.80	3.10	3.37	4.05
Zn30	1.15	10.79	0.310		0.350		0.375	0.450

Symbol	Ag47	Al13	Au79	Au79 (269)	Ba56	Bi83	C6	Co27	Cu29
Q	6.91	0.040	55.1		13.91	67.1	0.0018	0.75	1.00
k	17.8	4.45	32.54		22.67	34.48	1.98	9.73	10.49
λ	μ/ρ								
0.100	1.12	0.167	3.60	3.08		3.75	0.150	0.304*	0.335
0.110	1.32	0.171	4.28	3.81		4.50		0.345*	0.390
0.120	1.55	0.175	5.06	4.71	2.00†	*4.90*‡			0.460
0.130	1.85	0.185	5.90	5.75					0.545
0.140	2.20	0.195	6.90	6.96	2.80†			0.521*	0.640
0.145			*7.40*	*7.55*		2.25			
0.150	2.60	0.205			3.40†	2.44	0.153	0.75§	0.750
0.160	3.05	0.215	2.63	2.47	4.00†	2.90		0.687*	0.880
0.170	3.55	0.225	2.88		4.65†	3.32			1.03
0.180	4.10	0.235	3.30	3.16	5.40†	3.86		0.903*	1.18
0.190	4.75	0.246	3.76		6.47†	4.42		1.24§	1.34
0.200	5.47	0.267	4.25	4.11	7.45†	5.10	0.164	1.17*	1.51
0.220	7.20	0.302	5.50		9.20†	6.48		1.72§	1.90
0.240	9.20	0.349	6.95		11.7†	8.30	0.170	1.90*	2.41
0.260	11.6	0.405						2.53§	2.99
0.280	14.3	0.467			17.2†	12.5		2.90*	3.68
0.300	17.2	0.537		11.7			0.195	3.53*	4.38
0.320	20.4	0.623			*24.2*†	17.7			5.11
0.340	23.9	0.720			6.00	21.0	0.210		6.20
0.360	28.0	0.835							7.30
0.380	32.5	0.950							8.55
0.400	37.2	1.08			9.00		0.243		9.85
0.420	42.4	1.23							11.3
0.440	48.1	1.38			12.2		0.270		12.9
0.450	*50.2*						0.280		
0.460		1.54			14.0		0.288		14.6
0.480		1.72	51.7‖				0.300		16.4
0.500	9.55	1.95			17.8		0.325¶		18.4
0.550	13.0	2.46					0.378¶		24.2
0.586	15.5	3.00	64.5**	75.0††	26.3**		0.450¶	22.6§	29.0
0.631	19.4	3.70					0.550¶		36.7
0.709	26.2	5.21	122		41.3**		0.630¶	38.1§	51.0
0.748	33.0	6.20	*141*				0.750¶		60.0
0.910	57.0	10.8	165				1.25¶		102
1.000	73.0	14.2	*110*				1.50¶		133

* Calculated (219) from $\mu/\rho = 124\lambda^3 + 0.18$ if $0.1 < \lambda < 0.3$.

† Probably too low. ‡ Value for λ = 0.118.

§ From (343); too great if $0.150 < \lambda < 0.254$.

‖ Used *K*-radiation of a suitable substance (215); some of the values tabulated for Mg were obtained by interpolation.

¶ These values (5) do not agree even approximately with data for compounds; other data (189) are in very good agreement, *cf.* (250).

TABLE 5. II.—(*Continued*)

Symbol.	Fe26	H1‡‡	Li3	Mg12	Mo42§§	N7	Ni28	O8	Pb82
Q	0.65	1.4×10^{-6}	11×10^{-5}	0.029	4.40	0.0034	0.87	0.058	63.9
k	9.21	0.1663	1.145	4.01	15.84	2.31	9.68	2.64	34.19
λ	μ/ρ								
0.100	0.285	0.300					0.340	0.150	3.77
0.110	0.325						0.385		4.46
0.120	0.370			0.160			0.440		5.28
0.130	0.425			0.165			0.510		*6.20*
0.140	0.490			0.170			0.595		
0.150	0.565			0.175	1.93	0.160	0.690	0.160	2.37
0.160	0.645			0.186	2.32		0.795		2.70
0.170	0.735			0.196	2.72		0.930		3.10
0.180	0.830			0.207	3.10		1.07		3.55
0.190	0.940			0.220	3.52		1.23		4.05
0.200	1.07	0.316		0.232	4.02	0.180	1.40	0.180	4.62
0.220	1.38			0.260	5.20		1.77		5.85
0.240	1.72	0.323		0.293	6.60	0.197	2.22	0.204§§	7.35
0.260	2.16	0.326		0.330	8.25		2.80		9.20
0.280	2.68			0.375	10.10		3.40		11.3
0.300	3.23	0.333	0.175	0.430	12.4	0.222	4.10	0.243§§	13.6
0.320	3.90			0.480	15.0		4.85	0.259§§	16.2
0.340	4.60	0.340	0.185	0.570	17.7	0.248	5.75		19.7
0.360	5.35	0.343		0.660	20.5		6.70		23.0
0.380	6.26			0.760	23.6				27.2
0.400	7.24	0.350	0.210	0.875	27.0			0.336§§	31.8
0.420	8.0‖‖			0.995	30.5				36.5
0.440			0.225	1.13	34.6			0.385	41.2
0.450		0.358							
0.460				1.27	38.7				46.5
0.480				1.40	44.0				53.0
0.500	14.8††	0.366	0.250		48.6		18.5††	0.500	58.0
0.550	19.8††		0.275		63.8		24.4††		
0.586	23.1††	0.381	0.300		*75.0*¶¶		28.9††	0.71	74.5**
0.631	27.9††	0.388	0.361		13.8		34.8††	0.85	101
0.709	37.6	0.401		4.1**	19.5	1.1**	45	1.13	140
0.748	44.5	0.408			23.0		53	1.31§§	*145*
0.910	74.5	0.435			39.5		86	2.27§§	*150*
1.000	101	0.450			50.4		115	2.95§§	77

Symbol.	Pd46	Pt78	S16	Sn50	Th90	U92***	W74	W74	Zn30
Q	6.33	52.3	0.093	8.84	92.8	101	42.4	42.4	1.15
k	17.60	32.21	5.29	19.59	38.30	39.30	30.36	(269)	10.79
λ	μ/ρ								
0.100		3.65	0.190	1.16	*4.0*		3.37	2.67	0.375
0.110		4.35	0.195	1.45			4.05	3.29	0.450
0.120		5.14	0.200	1.80		1.87	4.83	4.03	0.530
0.130		6.05	0.225	2.20	1.96	2.27	5.72	4.93	0.630
0.140		7.08	0.250	2.60	2.25	2.56	6.75	5.91	0.750
0.145		*7.55*			2.48				
0.150			0.272	3.05	2.66	2.99	7.90	7.10	0.880
0.160			0.295	3.55	3.10	3.41	*8.90*	8.47	1.02
0.170		2.84	0.320	4.10	3.61			*9.99*	1.20
0.180		3.24	0.350	4.65	4.16				1.38
0.190		3.70	0.385	5.30	4.78		3.06		1.56
0.200		4.16	0.420	6.00	5.42		3.49		1.79
0.220		5.25	0.500	7.90	6.90		4.25		2.32
0.240		6.60	0.580	10.2	8.60		5.23		2.80
0.260			0.680	12.6			6.30		3.50
0.280		9.60	0.800	15.3			7.60		4.30
0.300	16.2	11.5	0.930	18.2			8.90		5.20
0.320		13.5	1.08	21.5			10.4		6.20
0.340	22.0	15.8	1.23	25.0			12.2		7.30
0.360	25.2	18.2	1.42	29.0			14.5		8.50
0.380		21.2	1.58	34.0			17.1		10.0
0.400	33.5	24.5	1.78	*39.5*		41	19.8		11.6
0.420		28.0	1.95				23.0		13.5

** From (343).

†† From (65).

‡‡ Values are computed from $\mu/\rho = 0.283 + \lambda/6$; for experimental values derived from observations on compounds containing H, *see* below (organic compounds). If $40 < \lambda < 100$, $\mu/\rho = 0.2\lambda^{2.25}$, *see* (193); *also* (233).

§§Interpolated from (250).

‖‖ From value (189) 8.12 at λ = 0.422.

¶¶ For λ = 0.600, $\mu/\rho = 81$.

*** Values for $0.4 < \lambda < 1.6$ are calculated from observed values (315) of $(\mu/\rho)_\lambda/(\mu/\rho)_{0.708}$ for U_3O_8 (*see* p. 16) on the assumptions that $(\mu/\rho)_\lambda$ for U is proportional to $(\mu/\rho)_\lambda$ for U_3O_8), and that for U $\mu/\rho = 41.0$ at λ = 0.400.

TABLE 5. II.—(*Continued*)

Symbol	Pd46	Pt78	S16	Sn50	Th90	U92***	W74	W74	Zn30
Q	6.33	52.3	0.093	8.84	92.8	101	42.4	42.4	1.15
k	17.60	32.21	5.29	19.59	38.30	39.30	30.36	(269)	10.79
λ	μ/ρ								
0.440	42.5	31.8	2.2	8.5			26.4		15.4
0.450	45.0					54			
0.460	47.7	36.0		9.6			30.0		17.5
0.480		40.5		10.9					19.7
0.500	*58.7*	45.5		12.0		71			22.0
0.550	11.5			15.8		*93*			28.1
0.586		73.5	5.90**	18.7			56.8**		34.3
0.631	17.2	87.0	6.90	22.6		88	*75.0*		43.0
0.709	23.9	117	9.8†††	32.1		*122*			59.0
0.748		*134*		39.0		57			69.9
0.910		170		66.0		92			115
1.000		*165*		87.0		120			152

Symbol	Ag47	Al13	Au79	C6	Cu29	Fe26	Mg12
Q	6.91	0.040	55.1	0.0018	1.00	0.65	0.029
k	17.80	4.45	32.54	1.98	10.49	9.21	4.01
λ	μ/ρ						
1.000	73.0	14.2	*110*	1.50¶	133	101	
1.090	95.0	18.0	88	2.00	165	127	15.7‖
1.170	113	22.5	104	2.40	206	158	20.0‖
1.293	146	30.0	137	3.20	*266*	207	
1.389	173			3.80	38.0		
1.432	192	40.3	179	4.30	42.0	280	36.6‖
1.537	225	50.0	210	4.90	50.0	324	
1.655	280	62.0	265	6.40	63.2	*424*	54.6‖
1.752	325	73.0		7.30		56.0	
1.933	410	93.0		9.20	97.0	70.0	82.8‖
2.25‖	580	136		15.3	143	104	126‖
2.500‡‡‡	696	182			202		
2.744‡‡‡	925	248			262		
3.026‡‡‡	*1330*	320			321		
3.353‡‡‡	1310	433			404		
3.432‡‡‡	*1460*						
3.592‡‡‡	*1360*						
4.146‡‡‡	461	771			621		
4.359‡‡‡	539	894			730		
5.394‡‡‡	852	1480			1300		
6.973‡‡‡	1260	*2800*			2120		
8.319‡‡‡	1770	344			3450		
9.868‡‡‡	2720	553			5030		
11.889‡‡‡		767			7550		

Symbol	Ni28	Pb82	Pt78	Sn50	U92	W74	Zn30
Q	0.87	63.9	52.3	8.84	101	42.4	1.15
k	9.68	34.19	32.21	19.59	39.30	30.36	10.79
λ	μ/ρ						
1.000	115	77	*165*	87.0	120		152
1.090	145	98	87	110	133		186
1.170		120	100	132			*226*
1.293	230	154	131	176	214	105	38.0
1.389		180	155	205			45.0
1.432	*311*	202	171	235	272	131	50.5
1.537	45.7	230	199	275	360		59.0
1.655	57.0	290	243	325			76.0
1.752	67.0	335	280	385	431		90.0
1.933	89.0	420	365	490	470		115
2.25‖	129		517				170
2.500‡‡‡	180		596				
2.744‡‡‡	239		756				
3.026‡‡‡	319		939				
3.353‡‡‡	384		1120				
3.592‡‡‡			*1370*				
4.146‡‡‡	627		*1290*				
4.359‡‡‡	735						
5.394‡‡‡	1250		*1640*				
6.973‡‡‡	2000		1190				
8.319‡‡‡	3140		1530				
9.868‡‡‡	4540		2440				

††† Another value (343) is 8.7.

‡‡‡ From Jönsson (*Diss.*, Upsala, 1928) replacing values, obtained by Allen with "end" radiations, referred to above. Objections to results obtained with λ in neighborhood of absorption limits are not valid here. Formula given after Table 3 can be used to calculate values of μ/ρ for other substances.

TABLE 5. II.—(*Continued*)

V	Br	C	Cl	I	S
	$\mu_\alpha/(\mu_\alpha)_N$ (301)				
1.4	4.72	0.60	2.20	34.50	1.80
0.9	4.30	0.60	2.28		2.02

H_2O, Water; $k = 2.972$

λ	μ/ρ	μ_m	λ	μ/ρ	μ_m	λ	μ/ρ	μ_m
0.100	0.167	0.496	0.220	0.212	0.630	0.440	0.400	1.19
0.110	0.171	0.508	0.240	0.223	0.662	0.500	0.500	1.48
0.120	0.175	0.520	0.260	0.234	0.695	0.550	0.600	1.78
0.130	0.178	0.529	0.280	0.246	0.731	0.586	0.686	2.04
0.140	0.180	0.536	0.300	0.259	0.769	0.631	0.812	2.41
0.150	0.183	0.545	0.320	0.273	0.811	0.709	1.08	3.21
0.160	0.187	0.555	0.340	0.290	0.861	0.783	1.38	4.10
0.170	0.190	0.564	0.360	0.309	0.918	0.881	1.95	5.79
0.180	0.194	0.576	0.380	0.330	0.980	0.929	2.18	6.47
0.190	0.198	0.588	0.400	0.352	1.05	0.977	2.52	7.48
0.200	0.201	0.597	0.420	0.376	1.12			

NaCl, Rock salt crystals (62, 63); *cf.* (20)

$\lambda = 0.589$ Å, Pl = reflecting plane, O = order of reflection, ϵ = extinction coefficient, E = relative amount of integrated energy reflected. $k = 9.645$; $\mu = 10.70$ cm²/g.

O	Pl	$\mu + \epsilon$	ϵ*	E
1	100†	16.30	5.60	100
1	110	13.60	2.90	50.5
2	200	12.66	1.96	19.9
3	300	10.72	0.02	4.87

* Secondary extinction only.

† For plane 100, Kirkpatrick (220) finds $\mu + \epsilon = 189\lambda^{3.9} + 0.43$ and $\epsilon = 1.90\lambda^{4.6}$, if $0.24 < \lambda < 0.58$.

Substance	Air	CO_2	SO_2	CH_3I*	C_2H_5Br*	U_3O_8 (315)
1000ρ	1.29	1.98	2.88	6.38	4.90	$\lambda_1 = 0.708$
k		7.26	10.57	23.42	17.98	
λ	μ/ρ (215)†					
K_{Ag}0.555	0.59		2.75	17.7	22.0	0.400 0.340
K_{Mo}0.692	0.98	1.42	5.56	30.9	42.9	0.450 0.450
K_{Sr}0.855	1.78	2.12	9.76	53.0	*66.8*	0.500 0.590
K_{Br}1.02	3.02		17.4	86.5	19.6	0.550 *0.770*
K_{Se}1.08	3.40	3.96	19.1	97	22.4	0.600 0.640
K_{As}1.15	4.10	5.00	22.9	116	26.1	0.631 0.730
K_{Zn}1.40	6.96	9.31	38.9	198	43.9	0.708 *1.000*
K_{Cu}1.51	8.43	11.5	46.5	241	53.1	0.750 0.480
K_{Ni}1.61	10.5	16.1	57.6	282	66.3	0.800 0.560
K_{Co}1.75	12.7		69.4		83.2	$k = 139.0$
K_{Fe}1.90	15.6	23.1	83.3	339	105	

* Values of μ are probably too small.

† Gowdy's values (165) differ from these.

Mica (322)

Line	KAgβ	KRhβ	KAgα	KRhα	KCuβ	KCuα	KCrβ	KCrα
λ	0.490	0.540	0.560	0.610	1.38	1.54	2.07	2.29
$\mu/2.8$	1.29	1.96	1.82	2.75	23.6	31.9	61.1	81.1

Formula	λ	0.187	0.207	0.227	0.247	0.272	0.318
	Substance*	$\mu_m/(\mu_m)_{H_2O}$ (19, 20)					
N_2H_4	Hydrazine	1.76	1.75	1.74	1.70	1.67	1.60
$C_2H_4O_2$	Methyl formate	3.14	3.14	3.12	3.08	3.06	3.01
C_3H_6O	Allyl alcohol	3.16	3.15	3.09	2.98	2.90	2.76
$C_3H_6O_2$	Propionic acid	3.92	3.90	3.86	3.82	3.76	3.74
$C_3H_6O_3$	Dimethyl carbonate	4.74	4.73	4.67	4.67	4.61	4.52
C_4H_8O	Methyl ethyl ketone	3.87	3.84	3.78	3.71	3.60	3.44
$C_4H_8O_2$	Ethyl acetate	4.66	4.64	4.60	4.51	4.41	4.25
C_6H_6	Benzene	4.04	4.00	3.94	3.84	3.75	3.45
$C_6H_{12}O_3$	Paraldehyde	7.04	6.86	6.83	6.70	6.57	6.42
C_7H_8	Toluene	4.87	4.83	4.72	4.60	4.40	4.10
C_7H_8O	Benzyl alcohol	5.64	5.57	5.52	5.42	5.24	4.95
C_8H_{18}	Octane	6.38	6.29	6.12	6.03	5.76	5.27
$C_8H_{18}O$	Octyl alcohol	7.17	7.07	6.96	6.84	6.62	6.13

Substance	H_2,† Hydrogen	C_6H_6, Benzene	$C_6H_{12}O$, Cyclohexanol	C_7H_8, Toluene	C_7H_{16}, Heptane	C_8H_{10}, Xylene	C_9H_{12}, Mesitylene
k_m	0.332	12.88	16.52	15.19	16.52	17.50	19.81
λ	μ/ρ (250); *cf.* (317)						
0.215	0.338						
0.2455	0.333	0.200	0.215	0.204	0.215	0.205	0.203
0.2782	0.531	0.215	0.227	0.214	0.225	0.216	0.210
0.3109	0.420	0.223	0.242	0.225	0.236	0.227	0.219
0.3436	0.449	0.237	0.255	0.238	0.248	0.239	0.232
0.3763	0.465	0.248	0.269	0.250	0.261	0.252	0.244
0.4089	0.385	0.263	0.289	0.265	0.277	0.268	0.261
0.4416	0.517	0.281	0.311	0.284	0.294	0.286	0.280
0.4905	0.459	0.309	0.348	0.312	0.320	0.314	0.309
0.5394	0.412	0.346	0.394	0.348	0.355	0.350	0.346
0.5883	0.333	0.391	0.449	0.393	0.397	0.394	0.391
0.6371	0.349	0.443	0.516	0.444	0.444	0.442	0.443
0.6859	0.489	0.504	0.592	0.504	0.499	0.506	0.502
0.7346	0.445	0.575	0.685	0.573	0.565	0.573	0.571
0.7833	0.450	0.657	0.787	0.650	0.638	0.652	0.650
0.8319	0.454	0.747	0.904	0.740	0.720	0.739	0.737
0.8804	0.637	0.850	1.03	0.840	0.812	0.840	0.831
0.9289	0.325	0.963	1.18	0.950	0.916	0.947	0.943
0.9773	0.457	1.09	1.34	1.07	1.03	1.07	1.07

Gelatin (244)‡

V	9.97	7.77	5.87	4.88	4.42	3.93	3.46	3.00	2.50
λ_{min}	1.24	1.59	2.10	2.53	2.78	3.14	3.56	4.11	4.95
μ/ρ	5.9	12.3	25.8	38.7	56.6	76.2	126	193	312

Celluloid (244)‡

V	5.87	4.88	4.42	3.93
λ_{min}	2.10	2.53	2.78	3.14
μ/ρ	25.6	42.5	60	81

If $40 < \lambda < 80$, $\mu/\rho = 0.2\lambda^{2.5}$; if $\lambda > 80$, the increase with λ is less rapid; μ/ρ passes through a maximum near $\lambda = 320$ Å (193, 194).

* For k, *see* Table 4.

† Values have been deduced (297) from observations (17, 250) on compounds; the probable error is large. Better values are given by the equation $\mu/\rho = 0.283 + \lambda/6$; *see* section devoted to the elements.

‡ Used "end" radiations of tube with Fe target. Values of μ/ρ are too great.

SCATTERING

For distinction between the two types (modified and unmodified) of scattered radiation, *see* p. 10. In most cases both types are measured together; from such measurements the coefficient (σ_s) of absorption due to true scattering can be obtained, but not that (σ) of total absorption due to scattering. To find that, we must also find either σ_a or both τ and μ ($\mu = \tau + \sigma = \tau + \sigma_a + \sigma_s$). As both σ_a and τ arise from loss of energy on account of the ejection of electrons from their energy-levels, it is exceedingly difficult to obtain either separately. Apparently, σ tends to 0 with λ. For values of λ of order of 0.01 Å, it is assumed that $\tau = 0$ for elements of low atomic number, and that σ/ρ is proportional to Z/A for all elements; for λ of order of 0.1 Å, $\sigma_s = (1 + \alpha)\,\sigma/(1 + 2\alpha)$, approximately, when Z is small, and practically $\sigma_s = \sigma$ for other elements. For values of σ_s/ρ, *see* Table 6. For variation of σ near absorption limits, *v.* (238).

If (θ) the angle of scattering is small, most of the scattered radiation is of the unmodified type; I_m/I_u increases with θ, but decreases as λ and Z increase, I_m and I_u being, respectively, the intensities of the modified and the unmodified radiation (*see* Table 7 and Fig. 2).

TABLE 6.—COEFFICIENTS OF MASS-SCATTERING

$\sigma = \sigma_s + \sigma_a$; σ_s/ρ is measured directly. In column λ, symbols of form γ_x indicate that filtered (through x cm of Pb) γ-rays from Ra(B + C) were used. In general, filtered X-rays have been used; then λ is the effective wave-length. Unit of $\lambda = 1$ Å $= 10^{-8}$ cm; of $\sigma_s/\rho = 1$ cm²/g.

TABLE 6.—(*Continued*)

	$\lambda_{eff.}$	σ_s/ρ	Lit.		$\lambda_{eff.}$	σ_s/ρ	Lit.
Al13.....	$\gamma_{1.5}$	0.0450	(198)	Li3.—	0.43	0.165	(243)
	$\gamma_{2.2}$	0.0360	(256)	(*Cont'd*)	0.54	0.157	(243)
	$\gamma_{2.6}$	0.0323	(247)		0.66	0.169	(243)
	0.082	0.130	(313)		0.71	0.168	(191)
	0.173	0.161	(313)		0.79	0.200	(243)
	0.225	0.147	(313)	Mg12....	$\gamma_{2.2}$	0.035	(198)
	0.373	0.156	(313)	Na23....	0.32	0.173	(243)
	0.458	0.260	(313)		0.43	0.191	(243)
	*	0.29	(120)		0.54	0.248	(243)
B5.....	0.32	0.154	(243)	Pb82....	$\gamma_{1.5}$	0.034	(198)
	0.43	0.162	(243)		$\gamma_{2.2}$	0.030	(256)
	0.54	0.169	(243)	Sn50....	$\gamma_{2.2}$	0.032	(256)
	0.66	0.165	(243)	Zn30....	$\gamma_{2.2}$	0.035	(256)
	0.79	0.179	(243)	H_2O.....	$\gamma_{2.6}$	0.0383	(247)
C6.....	0.081	0.116†	(5)		0.32	0.198	(243)
	0.32	0.166	(243)		0.43	0.206	(243)
	0.43	0.182	(243)		0.54	0.210	(243)
	0.54	0.194	(243)		0.66	0.216	(243)
	0.66	0.214	(243)		0.79	0.228	(243)
	0.71	0.200	(191)		0.161	0.185	(313)
	0.79	0.234	(243)		0.240	0.206	(313)
Cu29....	*	0.9	(120)		0.285	0.170	(313)
Fe26....	$\gamma_{1.5}$	0.042	(198)		0.501	0.201	(313)
Li3.....	0.32	0.133	(243)	NaCl....	0.41	0.234	(213)

	Substance	λ	σ_s/ρ	Lit.
$C_3H_8O_3$	Glycerol.....	$\gamma_{2.6}$	0.0406	(247)
C_6H_6	Benzene.....	0.709	0.238	(191)
C_8H_{18}	Octane.....	0.709	0.262	(191)
C_9H_{12}	Mesitylene.....	0.709	0.244	(191)
	Turpentine.....	$\gamma_{2.6}$	0.0352	(247)
	Filter paper.....	*	0.27	(120)

* Fairly soft X-rays, $\lambda_{eff.} = 0.75$ Å *ca.*

† From (5), assuming $\sigma/\rho = \mu/\rho$, and $\sigma_s = (1 + \alpha)\sigma/(1 + 2\alpha)$.

As values of σ given by the equation $\sigma = \mu - \tau$ (τ being obtained by means of an empirical equation) are considered misleading, they are not tabulated here.

TABLE 7.—RATIO OF INTENSITY OF THE MODIFIED (I_m) TO THAT OF THE UNMODIFIED (I_u) SCATTERED RADIATION

See also (135, 208, 210).* θ = angle of scattering; the atomic number follows the symbol of the scattering substance. If θ is small, I_u is much greater than I_m.

0.560 Å, $\theta = 120°$		0.709 Å, $\theta = 90°$	
(1)	I_m/I_u	(1)	I_m/I_u
(349)		(348)	
Li3.....	∞	Wood.....	2.73
Be4.....	8.72	Paraffin.....	4.69
B5.....	7.02	C6.....	1.45
C6.....	5.48	Al13.....	0.91
Na11.....	3.04	S16.....	0.42
Mg12.....	2.78	(280)	
Al13.....	2.61	C6.....	1.7
Si14.....	2.33	Al13.....	0.7
S16.....	1.91	S16.....	0.29
K19.....	1.72	Cu29.....	0.32
Ca20.....	1.71	Ag47.....	0.21
Cr25.....	0.75	Pb82.....	0.024
Fe26.....	0.51	(280)	
Ni28.....	0.40	0.631 Å, $\theta = 90°$	
Cu29.....	0.21	Al13.....	1.0

$\lambda = 0.709$ Å (Mo$K\alpha$) (348)					
(1)	Wood	Paraffin	C6	Al13	S16
θ	I_m/I_u				
60	1.19	2.29	1.08	0.46	
75	1.85	3.10	1.31	0.74	0.25
90	2.73	4.69	1.45	0.91	0.42
105	3.21	5.16	1.82	1.23	0.67
120	4.57	5.49	2.26	1.45	
135	5.38	6.52	3.42	2.11	
150	6.21	6.98	4.05	2.52	
165	7.00	7.47	4.86		

C6 (280)			$\theta = 120°$		
$\lambda = 0.709$ Å		λ	C6	Al13	Lit.
θ	I_m/I_u		I_m/I_u		
30	0.2	0.560	5.48	2.61	(349)
60	0.95	0.709	2.26	1.45	(348)
90	1.7				

* Davis and Mitchell (*Phys. Rev.*, Sept., 1928) have shown that, for carbon, the scattered radiation considered above as unmodified, contains as well as the truly unmodified radiation, rays of approximate frequency $(\nu - \nu_c)$. They found no evidence of scattered rays of greater frequency than that of the primary radiation. Their results have an important bearing on theories giving distribution of scattered radiation. The spectrum of the scattered radiation may depend on the intensity of the primary rays.

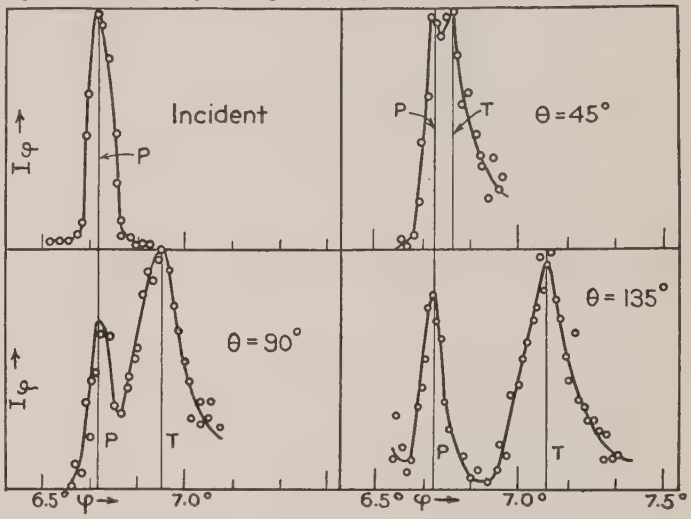

FIG. 2.—Change in wave-length on scattering (97-115). Radiation is Mo$K\alpha'$ line ($\lambda = 0.71$ Å); scatterer is graphite (C). P = position of primary; T = calculated position of line as modified by scattering; θ = angle of scattering; I_φ = intensity corresponding to spectrometer angle φ.

Change in Wave-length (Compton Effect).—All attempts based on the classical theory of radiation to explain the change of λ observed in the case of the modified radiation have been unsuccessful; this theory is, indeed, violated by the fact that the recoil electron is ejected at the same time as the scattered radiation is emitted (43, 54); *cf.* Fig. 2.

The energy and directions of emission and ejection of these electrons are those required by the quantum theory (114); and by assuming that the conservation principle of energy and of momentum apply to the electron and the quantum, each regarded as a single entity, it is possible to calculate the frequency of the radiation scattered in a given direction (θ) with reference to the primary beam (104, 105, 130). If the electron is free ($\nu_c = 0$) and initially at rest, the conservation equations are

$$h(\nu - \nu_\theta) = m_0c^2\left\{\frac{1}{\sqrt{1 - v^2/c^2}} - 1\right\}$$

and

$$\left(\frac{h\nu}{c}\right)^2 + \left(\frac{h\nu_\theta}{c}\right)^2 - \frac{2h^2\nu\nu_\theta\cos\theta}{c^2} = \frac{m_0^2v^2}{1 - v^2/c^2},\quad \lambda_\theta = \lambda + (0.0486\sin^2\theta/2)\ \text{Å},$$

and the energy ($E\varphi$) of a recoil electron ejected in the direction ϕ ($\leq 90°$) is $E\varphi = \{2h\ \nu\alpha\cos^2\varphi\} \div \{(1+\alpha)^2 - \alpha^2\cos^2\varphi\}$, where ν and λ refer to the incident radiation, and ν_θ and λ_θ to that scattered at the angle θ, v is velocity imparted to the electron, $\tan\varphi/2 = -\frac{\tan\theta}{1+\alpha}$, and φ, like θ, is measured from the direction of propagation of the incident beam; *see* (104). This change in λ is the same as, on the classical theory, would result from the Doppler effect if the initial velocity of the scattering electron were $c\alpha/(1+\alpha)$ and lay in the direction of propagation of the incident radiation; and, to a first approximation, it agrees with all the observed values (*see* Table 8).

Scattering by bound electrons has been similarly treated (108, 208). By taking into account the motion of the electron in its Bohr orbit, and assuming that the reaction between the electron and the impinging quantum is instanteous, a fair explanation only of the observed facts may be obtained (208); *cf.* (110). Unless the electron is dislodged from its energy level none of the scattered radiation is of the modified type. The frequency of the modified radiation scattered by electrons of a given energy level (characterized by ν_c) will have a definite maximum ($\nu - \nu_c$); hence the spectrum of the radiation scattered at a given angle should show a series of bands; they have not yet been observed. The short wave-length, $c/(\nu - \nu_c)$, corresponding to any level, coincides exactly with that which characterizes the radiation excited by photoelectrons coming from the same level, but, in spite of early evidence to the contrary, it is certain that photoelectrons do not excite an appreciable amount of such tertiary radiation (11, 40, 89–96, 100, 170, 172). For treatment of the Compton effect by the new quantum mechanics, *see* (140, 164, 222, 299, 332).

TABLE 8.—CHANGE IN WAVE-LENGTH ON SCATTERING (280)

$\delta\lambda_{obs.} = \lambda_\theta - \lambda$, where λ_θ = average wave-length of the modified band scattered at angle θ; $\delta\lambda_{calc.} = (0.0486\sin^2\theta/2)$ Å is the value calculated on assumption that the scattering electrons are initially free and at rest; atomic number and symbol of scattering substance are in column (1). $\delta\lambda_{obs.}$ has been found to equal $\delta\lambda_{calc.}$ for λ's lying between 0.211 Å and 0.709 Å, and for θ between 30 and 170°; *see* (11, 42, 72, 73, 75, 76, 105, 106, 107, 111, 115, 126, 170, 275–281, 302, 329, 346); the same is probably true for γ-rays from Ra, but the data are not conclusive, the values of λ and of λ_θ having been merely inferred from the observed coefficients of absorption in Pb; *see* (105, 192); *cf.* Fig. 2. Unit of λ and $\delta\lambda = 0.001$ Å $= 10^{-11}$ cm.

(1)	λ	θ	$\delta\lambda_{obs.}$	$\delta\lambda_{calc.}$
C6	709	30	3 ± 1	3
C6	709	60	12 ± 0.1	12.1
C6	709	90	23.6 ± 0.3	24.3
Al13	709	90	24.4 ± 0.1	24.3
Al13	631	90	24.2 ± 0.1	24.3
S16	709	90	24.0 ± 0.5	24.3
Cu29	709	90	24.4 ± 0.2	24.3
Ag47	709	90	23.8 ± 0.2	24.3
Pb82	709	90	24.0 ± 0.2	24.3

Distribution of Scattered Radiation (22–37, 62, 63, 104, 123, 128–130, 162, 319, 320).—Several attempts (*cf.* Table 9), all based on the assumption that the centers of scattering are the individual electrons external to the nucleus, have been made to derive an expression for $I_{s\theta\alpha}$ [$I_{s\theta m}$, $I_{s\theta i}$] in terms of θ and I, the intensity of the unpolarized incident radiation. All obtained are of the form $I_{s\theta\alpha} = \frac{1}{2}IF^2\eta(1+\cos^2\theta)$, where θ is the angle of scattering as measured from the direction of propagation of the incident radiation and $\eta = e^4/m_0^2c^4$. None of the expressions is entirely satisfactory. It is possible that one may be deduced from wave mechanics. Meanwhile, a qualitative explanation of the facts may be obtained as follows (174, 176, 210, 338). *U*-electrons scatter the radiation coherently, so that, if the number of *U*-electrons is known, the distribution of the modified radiation can be approximately computed by the method used in obtaining expression 2 (Table 9). *R*-electrons do not scatter the radiation coherently, so that, for wave-lengths of the order of 0.7 Å, $I_{s\theta\alpha}$ (*v.* Table 9) for the unmodified radiation would be equal to $\frac{1}{2}I\eta R_\theta(1+\cos^2\theta)\nu'/\nu$ (*v.* 1 of Table 9), R_θ being the number of *R*-electrons involved in scattering the modified radiation through the angle θ, ν' the frequency of this radiation, and ν that of the primary radiation. The above expression only holds for moderate wave-lengths, as $I_{s\theta}$ diminishes as ν increases (*see* 4, 5 of Table 9, and comments thereon).

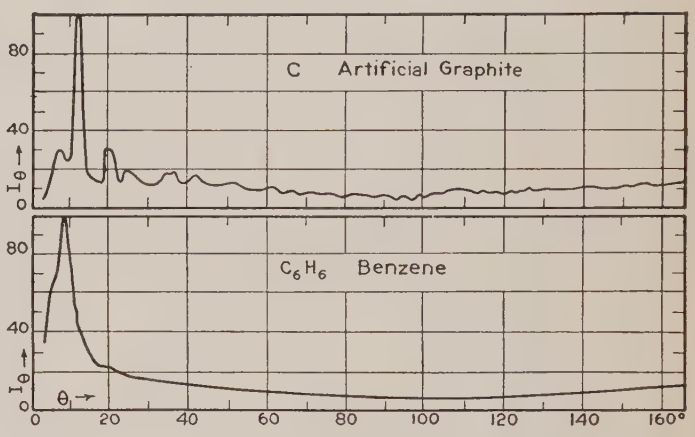

FIG. 3.—Scattering of X-rays by graphite (C) and benzene (C_6H_6) (189–191). The C_6H_6-curve is typical of the scattering by non-crystalline substances, the C-curve of that of crystalline substances. The difference between the two curves arises mainly from the difference in the regularity of the arrangement of the molecules in the two cases. Incident radiation consisted mainly of the Mo$K\alpha$ line ($\lambda = 0.71$ Å). I_θ = intensity of radiation scattered at angle θ.

All the theoretical expressions for F make it, and hence $I_{s\theta\alpha}$, a maximum when $\theta = 0$, and, for gases, $I_{s\theta m}$ in the region $0 \lesssim \theta < \pi/2$ (*cf.* (131)) has a single maximum at $\theta = 0$, so that the unmodified radiation is scattered coherently by single molecules (176). In solid and pure liquid radiators, in which the atoms are arranged in a more or less orderly manner, $I_{s\theta\alpha}$ apparently = 0 at $\theta = 0$ and has at least one maximum between $\theta = 0$ and $\theta = \pi/2$ (143, 191, 203); *cf.* (133, 216, 314, 351). *See* Fig. 3. This results from interference between the radiations scattered by the different atoms or molecules. The value of θ at which the maximum occurs is approximately proportional to λ. For some liquids there are 2 maxima (217, 218, 314), and for crystalline solids there may be many (*cf.* Fig. 3). For theories of scattering by liquids, *see* (131, 259, 352). Owing to such interference, correct values of $I_{s\theta\alpha}$, $I_{s\theta m}$, or $I_{s\theta i}$ for small values of θ cannot easily be derived from experiments on liquids or solids, except in certain cases with crystals, for which such expressions as 3 of Table 9 can be used; but as θ increases, the effect of interference appears to decrease. For distribution of radiation diffusely scattered from single crystals, *see* (203). For effect of temperature, *see* (61, 128, 200, 204, 357, 358).

Table 9.—Typical Formulae for the Scattering Function (F)

If incident radiation is unpolarized, $I_{s\theta\alpha} = \frac{1}{2}I\eta F^2(1 + \cos^2\theta)$; $\eta = e^4/m_0^2c^4$; $\alpha = h\nu/m_0c^2$; $\psi = (4\pi S_{mn}/\lambda)\sin(\theta/2)$, where S_{mn} = distance from the m'th to the n'th electron; E = total energy reflected at angle θ by a thick, ideally imperfect crystal rotating with a velocity of ω radians per sec, $\theta/2$ being the glancing angle at which the incident radiation (energy E_1 per sec) is reflected by the crystal, μ the effective absorption coefficient, N = number of scattering units* per unit of volume, and $e^{-[B(T)\sin^2\theta/2]/\lambda^2}$ is the Debye temperature coefficient (**128, 357, 358**). For other symbols, *see* p. 8.

Theory	F^2	$\sigma_{s\alpha}$	Lit.
1. †Thomson.....	Z, $\sigma_{a\alpha} = 0$	$8\pi Z\eta/3$	(319)
2. ‡Debye-Thomson...	$\sum_{m=1}^{m=Z}\sum_{n=1}^{n=Z}(\sin\psi)/\psi$, $\sigma_{a\alpha} = 0$		(129)
3. §Darwin-Compton..	$\frac{4E\omega\mu\sin\theta}{E_1N^2\lambda^3\eta(1+\cos^2\theta)}\cdot e^{[B(T)\sin^2\theta/2]/\lambda^2}$		(356, 123, 124)
4. ‖Compton.....	$Z\frac{(1+\cos^2\theta)+2\alpha(1+\alpha)(1+\cos\theta)^2}{(1+\cos^2\theta)(1+\alpha-\alpha\cos\theta)^5}$	$\frac{8\pi Z\eta(1+\alpha)}{3(1+2\alpha)^2}$	(105)
5. ‖Breit-Dirac.....	$Z\frac{1}{(1+\alpha-\alpha\cos\theta)^3}$	$2\pi Z\eta\cdot\frac{1+\alpha}{\alpha^3}\left\{\frac{2\alpha(1+\alpha)}{1+2\alpha}-\log_e(1+2\alpha)\right\}$	(66, 140)

* Unit = atom, molecule, etc., *see* (**63**).

† Has a very limited application, assumes that electrons scatter independently of each other. In any case, only holds over a moderate range of wave-lengths.

‡ Assumes there are no recoil electrons, that all the scattered radiation is unmodified in λ, and that the electrons have fixed positions relative to the nucleus; *cf.* (**104, 163, 295, 296**).

§ Has been used to determine F, which in this case is called the scattering factor, for atoms and ions in imperfect crystals, but only applies to the unmodified radiation, *see* (**174, 176, 210, 338**). For corresponding formula for perfect crystals, and discussion of problems arising from the fact that in practice crystals are not perfect, *see* (**124**); *cf.* (**60, 61, 110**).

‖ Based on quantum theories. Assumes the natural frequencies of the scattering electrons are small as compared with that of the incident radiation, all the scattered radiation then being of the unmodified type, and therefore incoherent. It requires that $\sigma = 0$ when $\lambda = 0$; for very small values of λ, it gives too small a value of σ, *see* (**177**).

Table 10.—Observed Distribution of Scattered Radiation

Incident radiation unpolarized. $I_{s\theta\alpha}$(or $I_{s\theta m}$ or $I_{s\theta i}$) = $\frac{1}{2}IF^2\eta(1+\cos^2\theta)$; $\eta = e^4/m_0c^4$ cgse units; θ = angle of scattering as measured from direction of propagation of incident radiation. Effect of interference (*see* above) has been ignored, hence values of F are only approximately correct. Gap = length of spark-gap; unit = 1 cm.

Scattering by atoms or molecules

Values of $(F_\theta/F_{90})^2$ are given below, *cf.* (**30, 97, 253, 359, 360**). Primary rays have not been obtained by reflection from crystals.

Paraffin wax (**177**), $\lambda = 0.012$ Å *ca.*

θ	33	45	67	90	110	130
$1+\cos^2\theta$.....	1.70	1.50	1.15	1.00	1.12	1.41
$(F_\theta/F_{90})^2$.....	5.05	3.33	1.65	1.00	0.63	0.43

Filter paper (**120**), unfiltered X-rays

Gap		1.0	1.5	2.1	3.5	4.0
θ	$1+\cos^2\theta$	$(F_\theta/F_{90})^2$				
10	1.97	1.86	1.88	2.15	2.18	2.33
15	1.92	1.69	1.80	1.87	1.69	1.49
20	1.88	1.54	1.60	1.46	1.45	1.22
25	1.81	1.39		1.26	1.29	1.09
30	1.71	1.22	1.22	1.13	1.20	
40	1.59	1.12	1.09	1.05	1.05	0.96
Substance (**157**)		Li	Na	K	H_2O	CH_3OH
θ	$1+\cos^2\theta$	$(F_\theta/F_{90})^2$, $\lambda = 0.19$ Å				
10	1.97	1.10	3.18	3.24	1.50	1.34
20	1.88	0.96	1.79	2.02	0.90	0.85
30	1.75	0.94	1.66	1.54	0.94	0.90
40	1.59	1.01	1.71	1.21	0.92	0.90
50	1.41	1.00	1.18	1.18	0.96	0.98
60	1.25	1.08	1.19	1.19	0.98	0.94
70	1.12		1.03	1.03	1.04	0.99
80	1.03	1.04	1.04	1.04	1.04	
90	1.00	1.00	1.00	1.00	1.00	1.00
100	1.03				1.02	
110	1.12				0.98	
120	1.25	0.96	0.98	0.98	0.96	
130	1 41				0.97	

Table 10.—(*Continued*)

Substance (**157**)	Li	Na	K	H_2O	CH_3OH
θ	$1+\cos^2\theta$	$(F_\theta/F_{90})^2$, $\lambda = 0.19$ Å			
140	1.59	0.95	0.79	0.79	0.98	0.93
150	1.75				1.01	
160	1.88	1.02	0.67	0.67	1.02	0.88

Cu (**212**); $\lambda = 0.41$ Å; $F_{90}^2 = 1.49Z = 43.2$

θ.....	40	50	60	70	80	90	100	110
$1+\cos^2\theta$...	1.59	1.41	1.25	1.12	1.03	1.00	1.03	1.12
$(F_\theta/F_{90})^2$....	3.26	2.41	1.68	1.60	1.44	1.00	0.97	1.03

Scattering by ions in single crystals

Data are derived from the intensities of reflected rays, and apply to the unmodified radiation only; they require correction for temperature, *v.* (**61, 128, 200, 354, 355, 357, 358**), and may contain small errors due to uncertainties in the values of the extinction coefficients. They indicate that as θ approaches zero, F approaches a value equal to the number of extranuclear electrons associated with the ion; *e.g.*, 10 in the case of Na^+. In each case, the number of such electrons is indicated by a subscript; *e.g.*, Na^+_{10}. t = 290°C.

NaCl, Rock salt

	$\lambda = 0.586$ Å (**61, 62, 63**)				$\lambda = 0.709$ Å (**185**); *cf.* (**183**)			
Ion	Na^+_{10}	Cl^-_{18}	Na^+_{10}	Cl^-_{18}	Na^+_{10}	Cl^-_{18}	Na^+_{10}	Cl^-_{18}
θ	F		F^2		F		F^2	
11.4	8.32	12.72	69.2	161.8				
12.5					9.00	13.6	81.0	185
15	7.61	10.59	57.9	112.1				
20	6.23	8.60	38.8	74.0	7.00	9.45	49.0	89.1
25	4.91	7.44	24.1	55.4				
30	4.01	6.50	16.1	42.2	4.48	6.72	20.1	44.2
35	3.37	5.78	11.4	33.4				
40	2.75	5.15	7.56	26.5	2.70	4.86	7.29	23.6
45	2.22	4.61	4.93	21.2				
50	1.76	4.15	3.10	17.2	1.75	3.56	3.06	12.7
55	1.37	3.70	1.88	13.7				
60	0.76	3.16	0.58	10.0	1.02	2.55	1.04	6.50
70					0.55	1.82	0.30	3.31
80					0.19	1.34	0.04	1.80

TABLE 10.—(*Continued*)

0.709 Å	NaF (185)		0.709 Å	LiF (185)		0.709 Å	CaF_2 (185); *cf.* (201)	
Ion	Na^+_{10}	F^-_{10}	Ion	Li^+_2	F^-_{10}	Ion	Ca^{++}_{18}	F^-_{10}
θ	F		θ	F		θ	F	
17.7	7.76	6.44	17.6	1.26	5.89	12.9	15.9	
20	7.25	5.90	20	1.25	5.5	20	12.9	6.00
30	5.13	3.65	30	1.00	3.4	30	9.7	3.35
40	3.47	2.08	40	0.70	2.22	40	7.3	2.25
50	2.22	1.43	50	0.45	1.55	50	5.75	1.58
60	1.40	1.00	60	0.31	1.07	60	4.76	1.23
70	1.10	0.70	70	0.17	0.75	70	3.76	0.93
80	0.82	0.55	80	0.13	0.58	80	3.00	0.70
90	0.55	0.46	90	0.10	0.47	90	2.62	0.52

For Al, *see* (38); *see also* (60, 61, 88, 110, 151, 178).

For effect of temperature on intensity of reflection of X-rays from crystals and latest interpretation of results such as those given above, *see* paper by James, Waller and Hartree, *5*, **118**: 334; 28.

RELATIONS BETWEEN ABSORPTION, SCATTERING AND ELECTRON EMISSION

On the quantum theory of absorption and scattering, the intensity of a radiation of frequency ν is $Nh\nu$, where N is the number of quanta of energy that pass per unit of time through a unit of area taken normal to the direction of propagation. Hence $I_x = I_0e^{-\mu x}$ is equivalent to $N_x = N_0e^{-\mu x}$, and if each scattered quantum were accompanied by a recoil electron, then σ/τ would equal N_R/N_τ, where N_R and N_τ are, respectively, the numbers of recoil- and of photo-electrons. But some of the scattered radiation (the unmodified) is not accompanied by recoil electrons, hence, in general, $\sigma/\tau > N_R/N_\tau$. These two ratios approach equality as λ and Z decrease, either separately or conjointly. The values of N_R and N_τ have been determined only for gases; for values and comparison of N_R/N_τ with σ/τ, *see* Table 11.

If $\nu > \nu_K$, where ν_K is the value of ν_c for the K-level, then more photoelectrons are emitted from the K-level than from all others (68, 273), and most of the absorption occurs in that level (*cf.* Fig. 1). In every case the relative numbers of photoelectrons ejected from the several levels depend on the relation of ν to the several values of ν_c, and none are ejected from those levels for which $\nu_c > \nu$; the absorption varies similarly. As the number of photoelectrons emitted with energy $h\nu$ is negligible, it is concluded that free electrons produce a negligible amount of photoelectric absorption. More photoelectrons are emitted in the direction of propagation of the incident radiation, than in the opposite direction (7, 134, 340, 341). Theories (14, 15, 78).

TABLE 11.—RELATION BETWEEN ABSORPTION AND THE NUMBER OF EJECTED ELECTRONS

N_R and N_τ = number of recoil electrons and of primary photoelectrons (those having energy = $h(\nu - \nu_c)$); σ and τ = coefficients of scattering and of photoelectric absorption; V = tube potential. If all the scattered radiation is of the modified type, then $N_R/N_\tau = \sigma/\tau$. For observations on recoil electrons produced by γ-rays, *see* (306). Unit of $\lambda = 1$ Å $= 10^{-8}$ cm; of range = 1 mm; of $V = 1000$ volt.

Homogeneous X-rays,* various gases (248); *cf.* (208)

Gas	λ	σ/τ	N_R/N_τ		N_R	N_τ
			Obs.	Calc.†		
N_2	0.614	0.42	0.286	0.340	116	406
O_2	0.614	0.28	0.194	0.227	119	613
Air	1.54	0.02	0			
Air	0.57	0.41	0.330	0.34	137	418
Air	0.55	1.75	1.58	1.61	153	97

Filtered X-rays, Air (113)

V	$\lambda_{eff.}$	σ/τ	N_R/N_τ	N_R	N_τ
21	0.71	0.27	0.10	5	49
34	0.44	0.12	0.9	10	11
52	0.29	3.8	2.7	33	12
74	0.20	10	9	74	8
84	0.17	17	17	68	4
111	0.13	34	72	72	1

* Rays reflected from a crystal.

† Calculated on assumptions of Jauncey (208).

APPARENT COEFFICIENT OF ABSORPTION

If the absorbing plate is placed very close to the ionization chamber, radiation scattered from the absorber enters the chamber. The apparent coefficient of absorption (μ') so obtained is less than the true. All the following data refer to such apparent coefficients. For effect of method of filtration on value of μ', *see* (177).

TABLE 12.—APPARENT COEFFICIENT OF ABSORPTION OF CERTAIN GROUPS OF γ-RAYS

Absorbing plate is close to ionization chamber. μ' = apparent coefficient of absorption; absorbing substance is indicated by subscript. Values of $(\mu'/\rho)_{Pb}$ are at end of table. Unit of $\mu'/\rho = 1$ cm²/g.

Source		$(\mu'/\rho)_{Al}$	Lit.
U-X_1...	90, 91	8.9*	(262)
		0.26	(262)
U-X_2...		0.052	(262)
Io.....	90	400	(82)
		8.35*	(82)
		0.15	
Ra.....	88	130	(284)
		6	(284)
		0.1	(284)
Ra-B...	82	87	(290)
		14.7*	(290)
		0.188	(290)
		0.21	(223)
Ra-C...	83	0.085	(224)
		0.047	(224)
		0.0424	(290)
Ra-D...	82	16.5*	(291)
		0.36	(291)
		17.2	(122)
		0.37	(122)
Ra-E...	83	16.5	(291)
		0.36	(291)
		0.092	(122)
Ra-F...	84	215	(284)
Rd-Ac..	90	9.3*	(292)
		0.070	
Ac-B....	82	44	(292)
		11.5*	(292)
		0.167	(292)
Ac-C''..	81	0.073	(292)
Ms-Th_2.	89	9.5*	(292)
		0.043	(292)
Th-B...	82	59	(292)
		11.8*	(292)
		0.13	(292)
Th-C''..	81	0.036	(292)

Source		$(\mu'/\rho)_{Pb}$	Lit.
U-X_1...	90	0.20	(180)
U-X_2...	91	0.064	(180)
Ra-B...	82	4.1	(263)
		0.53	
		0.41	(223)
		0.13	(263)
Ra-C ..	83	4.1	(263)
		0.53	(263)
		0.41	(223)
		0.13	(263)
		0.132	(148)
		0.0434	(263)
		0.047	(148)
Ms-Th_2.	89	1.00	(218)
		0.25	(218)
		0.062	(218)
Th-C''..	81	0.041	(308)

* Very close to value of $(\mu'/\rho)_{Al}$ for element's L-radiation.

TABLE 13.—MINIMUM APPARENT COEFFICIENT OF ABSORPTION OF γ-RAYS

Absorbing plates are close to ionization chamber. The radiation being quite heterogeneous, increasing the thickness of the absorbing plate increases the hardness of the transmitted radiation until μ' finally reaches a fixed minimum value, *cf.* (283, 308, 309). It is this minimum that is tabulated. (For variation of μ' with filtration, *see* Table 14.) Unit of $\rho = 1$ g/cm³; of $\mu' = 1$ cm^{-1}; of $\mu'/\rho = 1$ cm²/g.

Absorber	ρ	$100(\mu'/\rho)_{min}$			
		Th-C''	Ra-C	Ms-Th_2	U-X_2
Paraffin*.....	0.862	3.61	4.64	5.80	5.02
Glass.....	2.52	3.52	4.16	4.48	4.84
Magnesia†.....	1.92	3.23		4.69	4.78

TABLE 13.—(*Continued*)

Absorber	ρ	$100(\mu'/\rho)_{min}$			
		Th-C''	Ra-C	Ms-Th_2	U-X_2
Slate	2.854	3.37	4.14		4.69
Al, $Z = 13$	2.77	3.24	4.06	4.21	4.69
S,‡ $Z = 16$	1.785	3.69	4.38	4.65	5.16
Fe, $Z = 26$	7.62	3.28	3.99	4.15	4.72
Cu, $Z = 29$	8.81	3.34	3.98	4.23	4.72
Brass	8.35	3.25	3.89	4.25	4.70
Zn, $Z = 30$	7.07	3.30	3.93	4.24	4.65
Sn, $Z = 50$	7.245	3.26	3.88	4.21	4.70
Hg, $Z = 80$	13.59		4.72§		6.12
Pb, $Z = 82$	11.4		4.34‖	5.44	6.36

* Paraffin wax, values of μ'_{min} are high on account of presence of H.
† Magnesia brick.
‡ Values of μ'_{min} are probably too high.
§ Valid for thickness between 1 and 25 cm (283).
‖ Valid for thickness between 2 and 22 cm (309); *cf.* (308, 321).

TABLE 14.—APPARENT COEFFICIENT OF ABSORPTION OF FILTERED γ-RAYS

Rays from Ra(B and C). Unless the filtering is such that, for a thin plate of the absorber, $\mu' = \mu'_{min}$ of the absorber (*v.* Table 13), an additional filtering through the absorber will cause μ' to approach μ'_{min}. In general, the filtered rays are softened by transmission through a substance of lower atomic weight than the filter, and are hardened in the reverse case (167). For the following data the filter consisted of two plates: A "hardener" H of thickness f_h, and a plate of the absorber of thickness f_a. After passing through these plates in the order named, the apparent absorption (μ') of the rays by a second plate of the absorber, thickness x, is measured. The three plates are stacked close together and the plate of thickness x is in contact with the ionization chamber. Observed values of μ'/ρ may be compared with those of Table 13. Unit of f_a, f_h, and $x = 1$ cm; of $\mu'/\rho = 1$ cm²/g.

Absorber = Al (249), $x = 3.2$ cm

$f_a =$		0.2	3.4	6.6	9.8	13
H	f_h	$100\mu'/\rho$				
	0	9.57	4.27	4.23	4.24	4.23
Cu	2.4	3.58	3.85	4.02	4.03	4.04
Sn	2.5	3.18	3.51	3.71	3.83	3.81
Pb	0.2	3.54	3.75	3.85	3.96	3.99
Pb	1.1	2.92	3.21	3.41	3.61	3.64
Pb	2.0	2.77	3.15	3.23	3.41	3.48
Pb	2.9	2.67	3.01	3.22	3.30	3.38
Pb	3.8	2.52	2.92	3.15	3.27	3.35

Absorber = Fe (249)

$x =$		0.8	1	2	2	2	2	2
$f_a =$		0.2	1	2	4	6	8	10
H	f_h	$100\mu'/\rho$						
	0	4.53(?)		4.28	4.20	4.13	4.02	3.95
Al	7.5	4.58		4.21	4.08	4.02	3.97	3.94
Cu	2.4	4.16		4.11	4.02	4.01	3.93	3.92
Sn	2.5	3.56		3.84	3.86	3.90	3.89	3.89
Pb	0.2	3.83		3.96	3.98	3.97	3.96	3.92
Pb	1.1	2.91	3.37	3.53	3.67	3.76	3.78	3.83
Pb	2.0	2.79	3.15	3.39	3.57	3.70	3.72	3.76
Pb	2.9	2.75	3.07	3.32	3.51	3.64	3.68	3.70
Pb	3.8	2.71	3.04	3.29	3.50	3.61	3.67	3.70

Absorber—miscellaneous (81, 82)
Hardener = Pb; $f_a = 0$; x is not stated

$f_h =$	0.3	1.0	$f_h =$	0.3	1.0
Material	$100\mu'/\rho$		Material	$100\mu'/\rho$	
Air (gas)	4.8		CO_2	5.1	4.70
Air (liquid)	4.84	4.60	H_2O (liquid)	5.58	4.72
H	4.7*		Wood	5.21	4.29

* Apparently too small; *cf.* (1).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ahmad, *5*, **105**: 507; 24. (2) Ahmad and Stoner, *5*, **106**: 8; 24. (3) Allen, *2*, **34**: 296; 12. (4) Allen, *2*, **24**: 1; 24. (5) Allen, *2*, **27**: 266; 26. (6) Allen, *2*, **28**: 907; 26. (7) Allen and Alexander, *2*, **9**: 198; 17. (8) Allison, Clark and Duane, *197*, **10**: 379; 24. (9) Allison and Duane, *197*, **10**: 196; 24.
(10) Allison and Duane, *197*, **10**: 298; 24. (11) Allison and Duane, *197*, **11**: 25; 25. (12) Armstrong, Duane and Stifler, *197*, **10**: 374; 24. (13) Auger, *51*, **6**: 205; 25. (14) Auger, *34*, **180**: 1939; 25. (15) Auger and Perrin, *34*, **180**: 1742; 25. (16) Aurén, *3*, **33**: 471; 17. (17) Aurén, *3*, **37**: 165; 19. (18) Aurén, *147*, **4**: Nos. 3, 5; 20. (19) Aurén, *3*, **41**: 733; 21.
(20) Aurén, *147*, **4**: No. 10; 22. (21) Balderston, *2*, **27**: 696; 26. (22) Barkla, *3*, **7**: 543; 04. (23) Barkla, *3*, **11**: 812; 06. (24) Barkla, *3*, **15**: 288; 08. (25) Barkla, *201*, **15**: 257; 09. (26) Barkla, *3*, **21**: 648; 11. (27) Barkla, *3*, **22**: 396; 11. (28) Barkla, *5*, **92**: 501; 16. (29) Barkla, *62*, **217**: 315; 17.
(30) Barkla and Ayres, *3*, **21**: 270; 11. (31) Barkla and Collier, *3*, **23**: 987; 12. (32) Barkla and Dunlop, *3*, **31**: 222; 16. (33) Barkla and Nicol, *67*, **24**: 9; 11. (34) Barkla and Sadler, *3*, **14**: 408; 07. (35) Barkla and Sadler, *3*, **16**: 550; 08. (36) Barkla and Sale, *3*, **45**: 737; 23. (37) Barkla and White, *3*, **34**: 270; 17. (38) Bearden, *2*, **29**: 20; 27. (39) Beatty, *3*, **14**: 604; 07.
(40) Beatty, *5*, **89**: 324; 13. (41) Becker, *2*, **22**: 320; 23. (42) Becker, *197*, **10**: 342; 24. (43) Bennett, *197*, **11**: 601; 25. (44) Benoist, *250*, **1901**: 204. (45) Bergengren, *34*, **171**: 624; 20. (46) Blau, *75*, **127 IIa**: 1253; 18. (47) Blau and Altenburger, *96*, **25**: 200; 24. (48) Bohr and Coster, *96*, **12**: 342; 23. (49) Bohr, Kramers and Slater, *3*, **47**: 785; 24.
(50) Bothe, *96*, **16**: 319; 23. (51) Bothe, *96*, **20**: 237; 23. (52) Bothe, *63*, **26**: 410; 25. (53) Bothe, *96*, **40**: 653; 27. (54) Bothe and Geiger, *96*, **26**: 44; 24. (55) Bragg, *3*, **14**: 429; 07. (56) Bragg, *3*, **17**: 855; 09. (57) Bragg, *3*, **20**: 385; 10. (58) Bragg, *3*, **27**: 881; 14. (59) Bragg, *3*, **29**: 407; 15.
(60) Bragg and Bragg, *X-rays and crystal structure*. London, Bell, 1925. (61) Bragg, Darwin and James, *3*, **1**: 897; 26. (62) Bragg, James and Bosanquet, *3*, **41**: 309; 21. (63) Bragg, James and Bosanquet, *3*, **42**: 1; 21. (64) Bragg and Madsen, *3*, **16**: 918; 08. (65) Bragg and Peirce, *3*, **28**: 626; 14. (66) Breit, *2*, **27**: 242; 26. (67) Brillouin, *16*, **17**: 88; 22. (68) de Broglie, *34*, **172**: 274; 21. (69) de Broglie, *34*, **172**: 527; 21.
(70) de Broglie, *51*, **3**: 33; 22. (71) de Broglie, *B101*. (72) de Broglie, *34*, **178**: 908; 24. (73) de Broglie, *67*, **36**: 423; 24. (74) de Broglie and de Broglie, *34*, **178**: 383; 24. (75) de Broglie and Dauvillier, *34*, **179**: 11; 24. (76) de Broglie and Dauvillier, *51*, **6**: 369; 25. (77) de Broglie and Friedel, *34*, **176**: 738; 23. (78) Bubb, *3*, **49**: 824; 25. (79) Burbidge, *3*, **43**: 381; 22.
(80) Burbidge, *3*, **43**: 389; 22. (81) Chadwick, *67*, **24**: 152; 12. (82) Chadwick and Russell, *5*, **88**: 217; 13. (83) Chapman, *3*, **21**: 446; 11. (84) Chapman, *5*, **86**: 439; 12. (85) Chapman, *5*, **88**: 24; 13. (86) Chapman and Guest, *201*, **16**: 136; 11. (87) Chapman and Piper, *3*, **19**: 897; 10. (88) Claassen, *67*, **38**: 482; 26. (89) Clark and Duane, *197*, **9**: 126; 23.
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(110) Compton, *X-rays and electrons*. New York, Van Nostrand, 1926. (111) Compton and Bearden, *197*, **11**: 117; 25. (112) Compton and Hubbard, *2*, **23**: 439; 24. (113) Compton and Simon, *2*, **25**: 306; 25. (114) Compton and Simon, *2*, **26**: 289; 25. (115) Compton and Woo, *197*, **10**: 271; 24. (116) Crowther, *3*, **14**: 653; 07. (117) Crowther, *201*, **16**: 177; 11. (118) Crowther, *67*, **85**: 29; 11. (119) Crowther, *201*, **16**: 534; 12.
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(150) Eve, *3*, **18**: 275; 09. (151) Ewald, *63*, **26**: 29; 25. (152) Florance, *3*, **20**: 921; 10. (153) Florance, *3*, **27**: 225; 14. (154) Florance, *3*, **28**: 363; 14. (155) Fricke, *2*, **16**: 202; 20. (156) Fricke and Glasser, *197*, **10**: 441; 24. (157) Friedrich and Bender, *3*, **73**: 505; 24. (158) Friedrich and Glasser, *96*, **11**: 93; 22. (159) Glasson, *201*, **15**: 437; 10.

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(230) Kramers, *3*, **46**: 836; 23. (231) Kroenig and Friedrich, *Principles of physics and biology of radiation therapy*. New York, Rebman, 1922. (232) Kulenkampff, *96*, **19**: 17; 23. (233) Laird, *2*, **29**: 41; 27. (234) Lang, *3*, **53**: 279, 337; 17. (235) Laub, *63*, **14**: 992, 1209; 13. (236) Laub, *63*, **15**: 140, 342; 14. (237) Maizlish, *143*, **197**: 667; 24. (238) Mark and Szilard, *96*, **33**: 688; 25. (239) Martin, *201*, **23**: 783; 27.

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(310) Sogani, *Indian J. Physics*, **1**: 357; 27. (311) Stark, *63*, **10**: 902; 09. (312) Stark, *63*, **13**: 973; 12. (313) Statz, *96*, **11**: 304; 22. (314) Stewart and Morrow, *2*, **30**: 232; 27. (315) Stoner and Martin, *5*, **107**: 312; 25. (316) Takeuchi, *219*, **2**: 126; 20. (317) Taylor, *2*, **20**: 709; 22. (318) Thibaud, *34*, **179**: 815; 24. (319) Thomson, *Conduction of electricity through gases*. New York, Putnam, 1906.

(320) Thomson, *201*, **14**: 109; 07. (321) Tuomikoski, *63*, **10**: 372; 09. (322) Unnewehr, *2*, **22**: 529; 23. (323) Voltz, *63*, **16**: 306; 15. (324) Walter, *96*, **20**: 257; 23. (325) Walter, *96*, **30**: 357; 24. (326) Walter, *96*, **32**: 409; 25. (327) Warburton and Richtmyer, *2*, **23**: 291; 24. (328) Webster, *197*, **10**: 186; 24. (329) Webster and Ross, *197*, **11**: 224; 25.

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(340) Wilson, *5*, **104**: 1; 23. (341) Wilson, *5*, **104**: 192; 23. (342) Wingårdh, *96*, **8**: 363; 22. (343) Wingårdh, *Diss.*, Lund, 1923. (344) Wingårdh, *96*, **20**: 315; 23. (345) Woo, *197*, **10**: 145; 24. (346) Woo, *197*, **11**: 123; 25. (347) Woo, *2*, **25**: 444; 25. (348) Woo, *2*, **27**: 119; 26. (349) Woo, *2*, **28**: 426; 26.

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(360) Kohlrausch, *Radioactivität*, p. 17–189. Akad. Verlagsge. Leipzig, 1928.

EMISSION OF X-RAYS, WAVE-LENGTHS AND DATA ON ABSORPTION LIMITS[1,2]

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UNITS AND CONSTANTS

All quantities are expressed in cgse (cgs electrostatic) units unless others are indicated. Wave-lengths are expressed in Ångstrom units (Å), or in mÅ (1mÅ = 0.001 Å = 1XU = 10^{-11} cm), electrical potential in absolute volts (1 abs. volt = 10^8 cgsm unit = 3.3349×10^{-3} cgse unit = 0.99958 Int. volt (v)*) and in absolute kilo-volts (kv).

For the Rydberg constant (N_∞) and the Rydberg frequency (ν_∞) the following values, differing from the "derived" values given in Vol. I, p. 18, but agreeing with experimental determinations, are

* As defined by the equation, Weston normal cell at 20°C = 1.018300 Int. volt.

UNITÉS ET CONSTANTES

Toutes les unités sont exprimées en unités cgse (cgs électrostatique) à moins d'une autre indication. Les longueurs d'onde sont exprimées en unités d'Ångstrom (Å), ou en mÅ (1mÅ = 0,001Å = 1XU = 10^{-11} cm), le potentiel électrique en voltes absolus (1 volte abs. = 10^8 unités cgsm = $3,3349 \times 10^{-3}$ unités cgse = 0,99958 volte Int. (v)*) et en kilo-voltes absolus (kv).

Pour la constante de Rydberg (N_∞) et la fréquence de Rydberg (ν_∞) les valeurs suivantes, différant des valeurs "dérivées" données dans le Vol. I, p. 18, mais en accord avec les déterminations

* Tel qu'il est défini par l'équation, pile Weston normale à 20°C = 1,018300 volt Int.

[1] Data up to June, 1925, were collected by Webster and Nicholas, all data on the fine structure of absorption limits and the effects of chemical combination being collected by Nicholas and all other data by Webster. Owing to unavoidable delay in publication, it became desirable to add new data and to revise certain of the old so as to bring the report up to date. This was done for line spectra in December, 1927, by Siegbahn and for continuous spectra in May, 1928, by Nicholas.

[2] For data concerning the "*J*-phenomenon" and the polarization of X-rays, *see* p. 1 and p. 2.

used: $N_\infty = 109\ 737\ \text{cm}^{-1}$, $\nu_\infty = 3.29057 \times 10^{15}\ \text{sec}^{-1}$. Siegbahn's value ($d_c = 3.02904$ Å) for the grating space of calcite in first order is used.

NOTATION

General.—Except as otherwise defined, symbols are to be interpreted as defined in Vol. I, p. 16.

i	Cathode ray current reaching the target.
I_ψ	Apparent intensity: the value of ionization current obtained by complete absorption of J_ψ in the gas in the ionization chamber.
J_ψ	Intensity (energy) of radiation in direction ψ with reference to cathode rays.
j, k, n	Quantum numbers (*v.* p. 25).
N_∞	Rydberg's constant, commonly denoted by R.
S, s	Screening numbers (*v.* p. 29).
V	Electrical potential.
V_0	Excitation potential.
V_T	Tube potential: The effective accelerating potential acting upon the cathode rays.
Δ	Difference, *e.g.*, $\Delta\lambda$ = difference in wave-length.
ψ	Angle the direction of propagation of the observed beam of X-rays makes with the direction of propagation of the exciting cathode stream (*see* Fig. 19).
ν	Frequency, *not* reciprocal of wave-length.
ν_0	High frequency limit.
ν_∞	Rydberg's fundamental frequency.
$d\omega$	Elementary solid angle.

EINHEITEN UND KONSTANTE

Alle Grössen sind im cgse (cgs elektrostatisch)-Einheiten ausgedrückt, ausser es ist etwas anderes angegeben. Es sind ausgedrückt, Wellenlängen in Ångström Einheiten (Å) oder in mÅ (1mÅ = 0,001 Å = 1XU = 10^{-11} cm), das elektrische Potential in absoluten Volt (1 abs. Volt = 10^8 cgsm Einheit = $3{,}3349 \times 10^{-3}$ cgse Einheit = 0,99958 Int. Volt (v)*) und in absoluten Kilovolt (kv).

Für die Rydberg-Konstante (N_∞) und die Rydberg-Frequenz (ν_∞) werden Werte gebraucht, die von den "abgeleiteten" Werten abweichen, welche im Band I, S. 18 angegeben sind, aber mit den experimentellen Daten übereinstimmen, und zwar ist $N_\infty = 109\ 737\ \text{cm}^{-1}$, $\nu_\infty = 3{,}29057 \times 10^{15}\ \text{sec}^{-1}$. Es wird der Wert von Siegbahn für die Gitterkonstante erster Ordnung des Kalzits ($d_c = 3{,}02904$ Å) verwendet.

BEZEICHNUNGEN

Allgemeines.—Wenn nicht anders angegeben, die Symbole entsprechen den, welche im Bd. I, S. 16 festgelegt sind.

i	Auftreffender Kathodenstrahlenstrom.
I_ψ	Scheinbarer Intensität: der Wert des Ionisationsstromes der durch eine vollständige Absorption von J_ψ im Gase der Ionisationskammer erhalten wird.
J_ψ	Intensität (Energie) der Strahlung in der Richtung ψ mit Bezug auf die Kathodenstrahlen.
j, k, n	Quantenzahlen (*v.* S. 25).
N_∞	Rydberg-Konstante, meistens mit R bezeichnet.
S, s	Abschirmungszahlen (*v.* S. 29).
V	Elektrisches Potential.
V_0	Anregungspotential.
V_T	Röhrenpotential: das effektiv beschleunigende Potential, wirkend auf die Kathodenstrahlen.
Δ	Differenz, *d. i.*, $\Delta\lambda$ = Differenz in Wellenlänge.
ψ	Winkel den die beobachteten Röntgenstrahlen mit der Fortpflanzungsrichtung des erregenden Kathodenstrahlenbündeles bildet (*siehe* Fig. 19).

* Definiert durch die Gleichung, Weston-Normalelement bei 20°C = 1,018300 Int. Volt.

expérimentales, ont été utilisées: $N_\infty = 109\ 737\ \text{cm}^{-1}$, $\nu_\infty = 3{,}29057 \times 10^{15}\ \text{sec}^{-1}$. La valeur de Siegbahn ($d_c = 3{,}02904$ Å) pour la constante du réseau de la calcite est utilisée en premier lieu.

NOTATION

Généralités.—À moins d'une autre indication, les symboles doivent être interprétés comme définis dans Vol. I, p. 16.

i	Courant de rayons cathodiques atteignant l'anticathode.
I_ψ	Intensité apparente: la valeur du courant d'ionisation obtenu par l'absorption complète de J_ψ par le gaz dans la chambre d'ionisation.
J_ψ	Intensité (énergie) de la radiation dans la direction ψ par rapport aux rayons cathodiques.
j, k, n	Nombres quantiques (*v.* p. 25).
N_∞	Constante de Rydberg, communément désignée par R.
S, s	Constante de réduction (*v.* p. 29).
V	Potentiel électrique.
V_0	Potentiel d'excitation.
V_T	Potentiel du tube: le potentiel accélérateur effectif, agissant sur les rayons cathodiques.
Δ	Différence, *e.g.*, $\Delta\lambda$ = différence dans la longueur d'onde.
ψ	Angle que fait la direction de propagation du faisceau de rayons X observés avec la direction de propagation du courant cathodique d'excitation (*voir* Fig. 19).
ν	Fréquence, *non* réciproque de longueur d'onde.
ν_0	Limite de haute fréquence.
ν_∞	Fréquence fondamentale de Rydberg.
$d\omega$	Angle solide élémentaire.

UNITÀ E COSTANTI

Tutte le quantità sono espresse in unità cgse (cgs elettrostatico) a meno che non venga altrimenti indicato. Le lunghezze d'onda sono date in unità Ångstrom (Å) o in mÅ (1 mÅ = 0,001Å = 1XU = 10^{-11} cm), il potenziale elettrico in volte assoluti (1 ass. volta = 10^8 unità cgsm = $3{,}3349 \times 10^{-3}$ unità cgse = 0,99958 Int. volte (v)*) e in kilo-volte assoluti (kv).

Per la costante di Rydberg (N_∞) e per la frequenza di Rydberg (ν_∞) s'impiegano i valori seguenti che differiscono dai valori "derivati" (che sono dati nel Vol. I, p. 18) ma sono d'accordo con le determinazioni sperimentali: $N_\infty = 109\ 737\ \text{cm}^{-1}$, $\nu_\infty = 3{,}29057 \times 10^{15}\ \text{sec}^{-1}$. Per la distanza reticolare della calcite in primo ordine è usato il valore di Siegbahn ($d_c = 3{,}02904$ Å).

NOTAZIONE

Generalità.—Eccetto che venga altrimenti indicato i simboli devono venire interpretati secondo le definizioni indicate nel Vol. I, p. 16.

i	Corrente di raggi catodici che raggiungono il bersaglio.
I_ψ	Intensità apparente: valore della corrente di ionizzazione ottenuta per mezzo dell'assorbimento completo di J_ψ del gas nella camera di ionizzazione.
J_ψ	Intensità (energia) della radiazione nella direzione ψ rispetto ai raggi catodici.
j, k, n	Numeri quanta (*v.* p. 25).
N_∞	Costante di Rydberg comunemente denotata con R.
S, s	Numeri di schermo (*v.* p. 29).
V	Potenziale elettrico.
V_0	Potenziale di eccitazione.
V_T	Potenziale del tubo: il potenziale di accelerazione effettivo che agisce sopra i raggi catodici.
Δ	Differenza, per es., $\Delta\lambda$ = differenza in lunghezza d'onda.
ψ	Angolo che la direzione di propagazione del fascio di raggi X osservato fa con la direzione di propagazione del fascio dei raggi catodici eccitanti (*vedi* Fig. 19).

* Come definito dall'equazione, una pila normale Weston a 20°C = 1,018300 volt Int.

ν	Frequenz, *nicht* der reziproke Wert der Wellenlänge.
ν_0	Hochfrequenzgrenze.
ν_∞	Rydberg's fundamentale Frequenz.
$d\omega$	Elementarer fester Winkel.

ν	Frequenza, *non* il valore reciproco della lunghezza d'onda.
ν_0	Limite di alta frequenza.
ν_∞	Frequenza fondamentale di Rydberg.
$d\omega$	Angolo solido elementare.

TABLE 1.—NOTATION FOR NORMAL ENERGY-LEVELS, SERIES, AND SUBSERIES

Siegbahn* (142) 1918	M. de Broglie* (19) 1922	L. de Broglie and Dauvillier* (20) 1922	Bohr and Coster† (17) 1923	Bohr and Coster‡ (17) 1923	Sommerfeld§ (149) 1924	Russell and Saunders‖	Siegbahn* (142) 1918	M. de Broglie* (19) 1922	L. de Broglie and Dauvillier* (20) 1922	Bohr and Coster† (17) 1923	Bohr and Coster‡ (17) 1923	Sommerfeld§ (149) 1924	Russell and Saunders‖
K	K	K	K	1(1, 1)	K	H¶ 1^2S_1		N_3'	N_5				
L_3	L_3	L_3	L_I	2(1, 1)	L_{11}	Li 2^2S_1		N_2	N_4				
L_2	L_2	L_2	L_{II}	2(2, 1)	L_{21}	Li 2^2P_1	N_2	N_2	N_3	N_{VI}	4(4, 3)	N_{43}	K 4^2F_3
L_1	L_1	L_1	L_{III}	2(2, 2)	L_{22}	Li 2^2P_2	N_1	N_1	N_2	N_{VII}	4(4, 4)	N_{44}	K 4^2F_4
									N_1				
M_5	M_5	M_6	M_I	3(1, 1)	M_{11}	Na 3^2S_1							
M_4	M_4	M_5	M_{II}	3(2, 1)	M_{21}	Na 3^2P_1	O_5	O_5	O_6	O_I	5(1, 1)	O_{11}	Rb 5^2S_1
M_3	M_3	M_4	M_{III}	3(2, 2)	M_{22}	Na 3^2P_2	O_4	O_4	O_5	O_{II}	5(2, 1)	O_{21}	Rb 5^2P_1
M_2	M_2	M_3	M_{IV}	3(3, 2)	M_{32}	Na 3^2D_2	O_3	O_3	O_4	O_{III}	5(2, 2)	O_{22}	Rb 5^2P_2
M_1	M_1'	M_2(?)	M_V	3(3, 3)	M_{33}	Na 3^2D_3	O_2	O_2	O_3	O_{IV}	5(3, 2)	O_{32}	Rb 5^2D_2
	M_1	M_1					O_1	O_1	O_2	O_V	5(3, 3)	O_{33}	Rb 5^2D_3
									O_1				
N_7	N_8	N_{10}	N_I	4(1, 1)	N_{11}	K 4^2S_1							
N_6	N_7	N_9	N_{II}	4(2, 1)	N_{21}	K 4^2P_1	P_3	P_3	P_3	P_I	6(1, 1)	P_{11}	Cs 6^2S_1
N_5	N_6	N_8	N_{III}	4(2, 2)	N_{22}	K 4^2P_2	P_2	P_2	P_2	P_{II}	6(2, 1)	P_{21}	Cs 6^2P_1
N_4	N_5	N_7	N_{IV}	4(3, 2)	N_{32}	K 4^2D_2	P_1	P_1	P_1	P_{III}	6(2, 2)	P_{22}	Cs 6^2P_2
N_3	N_4	N_6	N_V	4(3, 3)	N_{33}	K 4^2D_3							
							Q	Q	Q	Q	7(1, 1)	Q_{11}	87 7^2S_1

* Subscripts are in inverse order of intensity of emission or absorption and in direct order of frequency of vibration; 1 denotes the subseries of most intense emission, which is the one of lowest frequency.

† This is known as the Bohr and Coster letter system. Subscripts denote the order in which the energy levels characteristic of the series are filled in a sequence of atoms proceeding in order of increasing atomic numbers.

‡ This is known as the Bohr and Coster number system. It specifies for each subseries all the quantum numbers known (in 1924) to be associated with it. The number outside the parenthesis is the *total* quantum number. In this section, the first of the two numbers in the parenthesis is regarded as the *azimuthal*, and the second as the *inner* quantum number; this is the opposite of the interpretation assigned by Sommerfeld's theory.

§ This is equivalent to the preceding notation.

‖ This is known as the alkali-metal-series term-system. The notation shows the optical term into which each X-ray term probably merges when followed through the series of elements to the alkali-metal in which it appears as an arc-series term. In elements a few units heavier than these alkali metals, the states of the valence electrons are quite different, and are in transition stages. The symbols are read thus: "One doublet S one," "Two doublet S one," "Two doublet P one," etc. (21, 104, 122, 139, 149, 150). Here the principal quantum numbers differ from those of (139), agreeing with more recent usage.

¶ Lyman's series-limit for H.

Quantum Notation.—In the Bohr and Coster number notation (17) (*see* Table 1), Sommerfeld's relativity doublet theory (149) assigns azimuthal quantization (k) to the second of the two numbers in the parenthesis, but later data (122, 123) indicate that it should be assigned to the first. For this reason k will be used in this section to denote the first of these numbers, and j, the second. Thus a level will be specified by the symbol $n(k, j)$; this preserves the physical significance of the symbols k and j but interchanges their assignments to the numbers used in the Bohr-Coster system. Here n is called the *total*, k the *azimuthal*, and j the *inner* quantum number. As they refer to different quantities, n may be $< k + j$.

TABLE 2.—NOTATION, RELATIVE APPARENT INTENSITIES, AND WIDTH: NORMAL LINES

In the X-ray section of I. C. T., the Siegbahn and the difference notations are used. In each series, the several groups of closely adjacent lines are indicated in Siegbahn's notation by distinctive letters, usually Greek, and the order of the intensities of the several lines of a group is indicated by numerical subscripts, subscript 1 denoting the strongest line; α_1, α_2, α_3, . . . is the order of decreasing intensity of the lines of the α-group. The series to which a given line belongs is indicated by prefixing the series letter; *e.g.*, $K\alpha_1$ is K-L_{22}; $L\alpha_1$ is L_{22}-M_{33}.

The normal intensities here given accord with the intensity-rules postulated by Ornstein, Burger, and Dorgelo for the optical spectra of the alkali-metals (1, 3, 94). Exceptions are found when the levels are not completely filled (90); *cf.* (91).

At the end of the table are given the widths ($\Delta\lambda$) of certain spectral lines, both in XU and in equivalent volts (ΔV) as defined by $\Delta V = 12\,346\frac{\Delta\lambda}{\lambda^2}$, in which both $\Delta\lambda$ and λ are expressed in Ångstroms.

K-Series. I_r is independent of voltage (175).

B	Sn	B and D	D and P	Sd	Dif.	I_r
Bragg	Siegbahn	de Broglie and Dauvillier	Davis and Purks (53.1)	Sommerfeld	Difference	Relative intensity*
α_2	α_2	α_2	α_2	α'	K-L_{21}	50
α_1	α_1	α_1	α_1	α	K-L_{22}	100
β	β_3	β_1'	β_2	β'	K-M_{21}	35
	β_1	β_1	β_1	β	K-M_{22}	
γ	β_2	γ_1	γ	γ	K-$N_{21,22}$	15
	β_4				K-$O_{21,22}$	W†

TABLE 2.—(*Continued*)

L-Series. Relative intensities in L_{22} subseries are independent of voltage. Within each subseries, relative intensities maintain constant ratios. Intensities in L_{21} and L_{11} subseries are estimated on the basis of a correction to extremely high voltages, the line α_1 serving as a standard.

Sn	B and D	Sd	Dif.	I_r		
				74W‡	78Pt‡	90Th§
β_4	β_4	φ'	L_{11}-M_{21}	5.2		
β_3	β_3	φ	L_{11}-M_{22}	8.2	(8.2)	3.3
γ_2	γ_7	χ'	L_{11}-N_{21}	1.48		1.5
γ_3	γ_3	χ	L_{11}-N_{22}	2.01		
γ_4	γ_4	ψ', ψ	L_{11}-$O_{21,22}$	0.59		
	γ_8‖		L_{11}-$P_{21,22}$			
η	η	η	L_{21}-M_{11}	1.3	1.5	1.8
β_1	β_1	β	L_{21}-M_{32}	51.8	50.8	62
γ_5	γ_5	κ	L_{21}-N_{11}	0.41		
γ_1	γ_1	δ	L_{21}-N_{32}	9.1	11.1	14
γ_8	γ_6, γ_{10}¶	μ	L_{21}-O_{11}			
γ_6	γ_2	ϑ	L_{21}-O_{32}	0.3		5.3
	γ_2'**		L_{21}-P_{11}			
l	l	ϵ	L_{22}-M_{11}	3.2	3.4	3.6
α_2	α_2	α'	L_{22}-M_{32}	11.5	11.4	12
α_1	α_1	α	L_{22}-M_{33}	100.0	100.0	100.0
β_6	β_6	ι	L_{22}-N_{11}	1.0		1.4
	β_2'					
β_2	β_2	γ', γ	L_{22}-$N_{32,33}$	20.0	22.7	26
β_7	β_7'	λ	L_{22}-O_{11}			
β_5	β_5	ζ', ζ	L_{22}-$O_{32,\ 33}$	0.2	3††	
	β_5'**		L_{22}-P_{11}			
β_9				0.7		
β_{10}				0.7		

M-Series. I_r is photographic estimate ([83, 149]): no ionization measurements available. Not corrected for voltage, hence not reliable at low voltages.

Sn	Sd	Dif.	I_r*
	χ'	M_{11}-N_{21}	0
	χ	M_{11}-N_{22}	1
		M_{11}-O_{22}	0
		M_{11}-P_{22}	0
	δ	M_{21}-N_{32}	1
	ϑ	M_{21}-O_{32}	0
	η	M_{21}-N_{11}	1
	γ'	M_{22}-N_{32}	2
γ	γ	M_{22}-N_{33}	
	ζ'	M_{22}-O_{32}	1
	ζ	M_{22}-O_{33}	
	ϵ	M_{22}-N_{11}	1
		M_{22}-O_{11}	0
β	β	M_{32}-N_{43}	5
		M_{32}-O_{21}	1
α_2	α'	M_{33}-N_{43}	1
α_1	α	M_{33}-N_{44}	8
		M_{33}-N_{22}	1
		M_{33}-P_{22}	0

N-Series. No values of I_r available.

Sn	Sd	Dif.	I_r*
	β	N_{21}-O_{32}	
	α'	N_{22}-O_{32}	
	α	N_{21}-O_{33}	

TABLE 2.—(*Continued*)

Width of certain spectral lines ([76, 77])

Unit of λ and Δλ = 1 XU = 0.001 Å = 10^{-11} cm; of ΔV = 1 volt

Line	λ	Δλ	ΔV	
Cu$K\alpha_1$	1537	0.35	1.8	
Cu$K\beta_1$	1389	0.58	3.7	
Mo$K\alpha_1$	708	0.19	4.8	
Mo$K\beta_1$	631	0.21	6.4	±15%
Mo$K\beta_3$	632	0.25	7.8	±30%
Rh$K\alpha_1$	612	0.19	6.3	
Rh$K\beta_1$	544	0.25	10.4	±15%
Rh$K\beta_3$	545	0.30	12.4	±30%
Ag$K\alpha_1$	558	0.24	9.4	
W$L\alpha_1$	1473	0.78	4.4	
W$L\beta_1$	1279	0.73	5.5	16‡‡
W$L\beta_1$	1279	0.71	5.3	8‡‡
W$L\beta_1$	1279	0.69	5.2	4‡‡
W$L\gamma_1$	1096	0.67	6.9	12‡‡
W$L\gamma_1$	1096	0.64	6.5	8‡‡
W$L\gamma_1$	1096	0.53	5.4	4‡‡

* With reference to W unless otherwise indicated. For other values for *K*-series, *see* Table 6.

† Very weak.

‡ Measured by Geiger-method, and corrected for voltage and absorption ([94]).

§ Measured by ionization-method, and corrected for voltage and absorption ([1]).

‖ For U ([47]).

¶ γ_6 for W and Ce; γ_{10} for Ba.

** For Au ([47]).

†† This measurement ([183, 184]) was incidental to other work, and probably is less reliable than other values, but similar changes with *Z* have been observed photographically ([44]).

‡‡ This is the current expressed in milliamperes; 16mÅ, etc.

TABLE 3.—NOTATIONS: NON-DIAGRAM LINES

The I. C. T. uses Siegbahn's and difference notations

Siegbahn	Dauvillier	Duane	Difference
K-series (*see* ([19])); found only in elements *Z* = 11Na to *Z* = 30Zn, and *Z* = 42Mo*			
α''	α''		
α'	α_7		
α_3	α_3		
		α_3†	K-L_{11}
α_4	α_4		
α_5	α_5		
α_6	α_6		
β'	β'		
β''	β''		
β_3‡	β_3‡		K-M_{11}(?)
	γ_2		K-N_{32}(?)
L-series§			
β_{10}	β_9		L_{11}-M_{32}
β_9	β_8		L_{11}-M_{33}
β_8	β_2''		L_{22}-N_3‖

* The *K*-lines found ([53.2]) for Mo and called α_1', α_2', β_1' have not yet been identified in the accepted notations.

† Reported ([68]) in W spectrum with intensity ([71]) = 0.04I $K\alpha_1$, but Crofutt ([42]) and others have looked for it without success. It has not been reported for elements 11 to 30.

‡ Not the $K\beta_3$ of the normal series.

§ Nomenclature is confused, wave-length data are conflicting. The correspondences given were obtained by comparing (([142]) p. 112, 172) with (([19]) p. 100). For other lines, *see* Table 11.

‖ de Broglie's notation.

ORIGIN OF X-RAYS

Line Spectra.—X-rays belonging to line spectra are produced by radiation, as quanta, of the energy released in the readjustments of atoms from which electrons have been removed. The removal of such electrons may be accomplished either by direct action of cathode rays or by indirect action, through the photoelectric effect of the rays from the continuous spectrum produced by the cathode rays; rays due to these processes are called direct and indirect rays, respectively. The ratio, direct to indirect, is about 6 or 7 for Cu with 15 to 20 kv (**11.1**); about 1.9 for Ag with 35 to 80 kv (**182**). For any element, this ratio may vary somewhat with the voltage, but not rapidly.

Continuous Spectra.—X-rays of the continuous spectrum are probably produced by transitions of cathode rays from large to small hyperbolic orbits passing near atomic nuclei (**100**), or, better, between corresponding non-periodic wave systems.

In accordance with Einstein's relation, radiation of frequency ν will not be emitted unless the energy (eV) of the impinging cathode particle is at least as great as $h\nu$. Hence, for each value of V, there is a definite high-frequency limit (ν_0) to the emitted radiation.

Such a high-frequency limit to the continuous spectrum is observed. Its value is independent of the angle the X-rays make with the cathode rays (tested for angles between 45 and 155°) (**62, 170, 180**), and is not changed (**14**) when the current density at the focal spot is varied in the ratio of 1 to 5. The ratio V/ν_0 has been studied for the elements 24Cr, 28Ni, 29Cu, 42Mo, 45Rh, 46Pd, 47Ag, 73Ta, 74W and 78Pt, and has been found to have an absolute value which is constant within the limits of experimental error; *i.e.*, within 1% for 4.5 kv $< V <$ 100 kv, and within 5% for 100 kv $< V <$ 245 kv (**16, 43, 54, 61, 87, 88, 107, 124, 168, 170, 174, 175, 184**); general reviews (**142, 171, 179**). Hence h may be derived from V/ν_0, if e is known.

PLANCK'S CONSTANT (h)

The most accurate determination of h by X-ray methods is that derived by Duane, Palmer, and Yeh (**62**) from the observed high-frequency limit (ν_0) of the continuous spectrum of W. Assuming that the grating space of calcite (d_c) = 3.028 Å and that e and c have the values given in Vol. I, p. 17, they obtained $h = (6.556 \pm 0.009) \times 10^{-27}$ erg sec. Using the more accurate value (**140, 142**), d_c = 3.02904 Å, this becomes

$$h = (6.558 \pm 0.009) \times 10^{-27} \text{ erg sec}$$

which exceeds the I. C. T. value (Vol. I, p. 17) by 0.06%.

Assuming $h = 6.558 \times 10^{-27}$ erg sec and $e = 4.774 \times 10^{-10}$ es, exactly, Einstein's equation leads to the relations:

$$\nu_0 V = 2.4277 \times 10^{14} \text{ (volt sec)}^{-1}$$
$$= 2.4287 \times 10^{14} \text{ (Int. volt* sec)}^{-1}$$
$$V\lambda_0 = 1.2352 \times 10^{4} \text{ volt Å}$$
$$= 1.2346 \times 10^{4} \text{ Int. volt* Å}$$

LINE SPECTRA

General Characteristics.—In the characteristic line spectrum of any element, most of the lines can be distributed among a small group of series and subseries in accordance with the conception of energy-levels. Every line in any series is regarded as arising from the return of an electron to some one of the levels composing a single group, and all lines belonging to the same subseries involve the same group with the same electronic readjustments during ionization. In any given subseries, no line appears unless (eV) is at least equal to $h\nu_0$, where ν_0 is the highest frequency represented in the subseries; ν_0 is a characteristic of the subseries, and is known as the subseries limit. The value of $V_0 = h\nu_0/e$ is called the *excitation* voltage of the subseries; it may be computed from data in Table 10 or from the wave-length of the absorption limit (Table 11) of the subseries. The former method is probably the more accurate. Certain values of V_0 are given in (**142**). Accuracy of confirmatory data is about 1% (**45, 85, 88, 137, 169, 174, 175, 178, 184, 196**). The distribution of electrons in atoms and the transitions involved in the emission of characteristic X-rays are indicated in Figs. 1 and 2.

The lines which do not obey the laws followed by the normal series are referred to anomalous energy-levels. All these lines are very faint and may arise from multiple ionization (**35, 46, 189**) but opinions differ regarding their sources (*see, e.g.* (**6**)). Hence, data and notations pertaining to anomalous levels must be considered as tentative only. All lines not definitely related to the normal levels and those not obeying the selection rules (p. 31) will be called *non-diagram* lines, and will be designated by the notation used by the investigator quoted. For excitation voltages of certain non-diagram lines, *see* Table 9, 13Al, 26Fe, and 42Mo.

The various symbols which are used for specifying the energy-levels, series and subseries are given in Table 1.

Proceeding in the order of the atomic numbers, the spectra of successive elements are found to be very similar, and to undergo a regular displacement from element to element (Figs. 3 and 4); for any given line, this displacement is such that $\sqrt{\nu}$ is nearly linear in Z (Moseley's law) (*v.* Table 4). Lines so related may be called corresponding lines. Semi-optical lines (*cf.* Fig. 4) occupy anomalous positions.

Bäcklin (**7, 8**) and Ray (**134**) have shown that, when one of the lighter elements (13Al, 14Si, 15P, 16S) enters into certain chemical compounds, the wave-length of its $K\alpha$-lines is slightly changed; the following differences, expressed in x-units (1 XU = 0.001 Å), were observed by Bäcklin (**7**): Al and Al_2O_3, $\delta\lambda$ = 1.72; Si and SiO_2, $\delta\lambda$ = 2.34; red P and either P_2O_5 or Na_3PO_4, $\delta\lambda$ = 2.72; and S and $BaSO_4$, $\delta\lambda$ = 3.05. Likewise their $K\beta$ lines change both in intensity and wave-length (**115, 116, 117, 120, 129, 130**).

TABLE 4.—VARIATION OF FREQUENCY WITH ATOMIC NUMBER

If $\nu_\infty = 3.29057 \times 10^{15}$ sec^{-1}, and ν is the frequency of a given line in the spectrum of the element of atomic number Z, then* $\sqrt{\nu/\nu_\infty} = a + bZ(10)^{-3} + cZ^2(10)^{-6}$. With the values of the coefficients given below, the computed value of $\sqrt{\nu/\nu_\infty}$ is seldom in error by as much as 0.2 unit, if $Z > Z_0$.

Line	Difference	a	b	c	Z_0
Ll	L_{22}-M_{11}	−2.99	369	− 191	37
$L\alpha_1$	L_{22}-M_{33}	−2.09	352	+ 159	29
$L\eta$	L_{21}-M_{11}	−1.13	280	+1051	36
$L\beta_4$	L_{11}-M_{21}	−0.45	287	+1041	36
$L\beta_1$	L_{21}-M_{32}	−0.44	274	+1264	29
$L\beta_3$	L_{11}-M_{22}	+0.06	263	+1345	36
$L\beta_2$	L_{22}-$N_{32,33}$	−3.82	412	+ 81	39
$L\gamma_1$	L_{21}-N_{32}	−2.29	338	+1116	39
$L\gamma_2$	L_{11}-N_{21}	−1.54	333	+1126	36
$L\gamma_3$	L_{11}-N_{22}	−1.26	321	+1244	36
$L\gamma_4$	L_{11}-$O_{21,22}$	−1.33	324	+1315	48
	L_{11}-limit	−0.37	288	+1638	46
	L_{21}-limit	−0.45	274	+1712	46
	L_{22}-limit	−3.20	384	+ 400	46
$K\alpha_2$	K-L_{21}	+0.12	788	+1406	10
$K\alpha_1$	K-L_{22}	−0.03	798	+1330	10
$K\beta_1$	K-M_{22}	−0.71	868	+1246	10
$K\beta_2$	K-N_{22}	−0.47	856	+1587	22
	K-limit	−0.60	862	+1539	11

* Defined by the relation: Weston normal cell = 1.018300 Int. volt at 20°C.

* Computed in editorial office from data (**142**) submitted by Expert. No attempt to get a "best fit."—Ed.

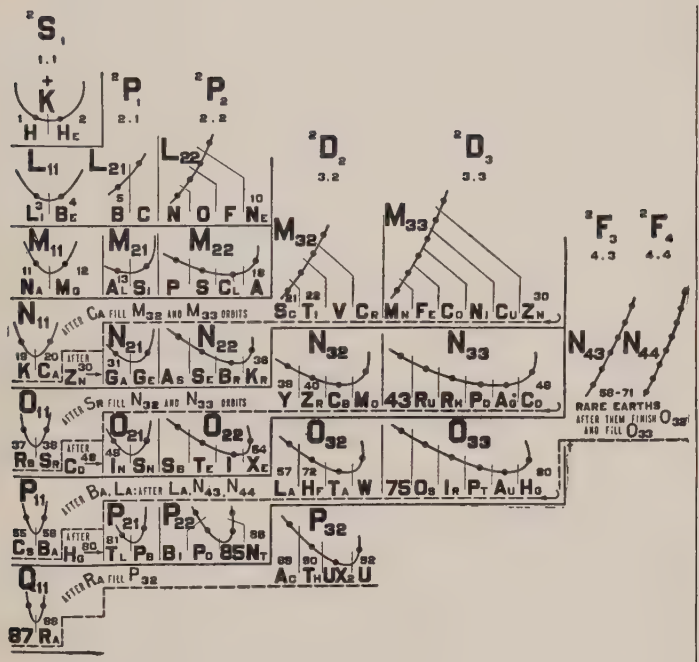

FIG. 1.—Distribution of electrons in atoms according to Stoner's modification (156) of Bohr's theory.

For discussion of experimental evidence, *see* (10, 22, 149, 151, 156).

Each energy-level, presumably corresponding to a group of orbits, is represented by an arc with as many dots as there are electrons in the heaviest element. The number of such electrons for a given element is indicated by the distribution of the dots. The shape of the arc indicates qualitatively the probable character of the orbit. Evidence more recent than Stoner's theory (*v.* Slater (148)) indicates that the distinction between orbits differing only in an inner quantum number (*e.g.*, L_{21} and L_{22}) may be the unreal; that, for example, all 6 electrons in the L_{21} and L_{22} orbits may belong to a single group, and that the division in $2L_{21}$'s and $4L_{22}$'s may be merely a statistical expression of the chances of 2 forms of readjustment of the group when one electron is removed.

Each element contains as many electrons as there are units in its atomic number, distributed, in general, as follows: Beginning at the top and proceeding in order of atomic numbers, the electrons in an element are distributed in accordance with all the dots up to and including that associated with its own symbol; *e.g.*, of the 13 electrons of Al, 2 are in each of the orbits K, L_{11}, and L_{21}, 4 in L_{22}, 2 in M_{11}, and 1 in M_{21}. This rule is fairly certain for all elements in the S-column, but the P orbits are not always filled in the order indicated and exceptions are very probable in the filling of the D and the F orbits; and any incomplete group (such as a group of 4 P-electrons) of equal total quantum number becomes a unit giving rise to series more complex than doublets.

In general, the X-ray spectrum of an element will contain no normal X-ray line which involves a level not shown in this diagram, but exceptions occur; *e.g.*, the line K-$M_{21,22}$, arising from a temporary occupancy of the $M_{21,22}$ orbits (10), is observed in the spectrum of Na and Mg. As compared with the usual normal lines, these lines occupy an anomalous position in the spectrum (*see* Fig. 4); they are called semioptical lines.

Univalent Cu probably takes one of its N_{11} electrons to complete M_{33}; Ag one of its O_{11}'s into N_{33}; and Au, one of its P_{11}'s into O_{33}.

The rare earths (58 to 71), Sc21, Yt39, La57, and Ac89, all have similar sets of valence electrons (those beyond the outermost X-ray orbit).

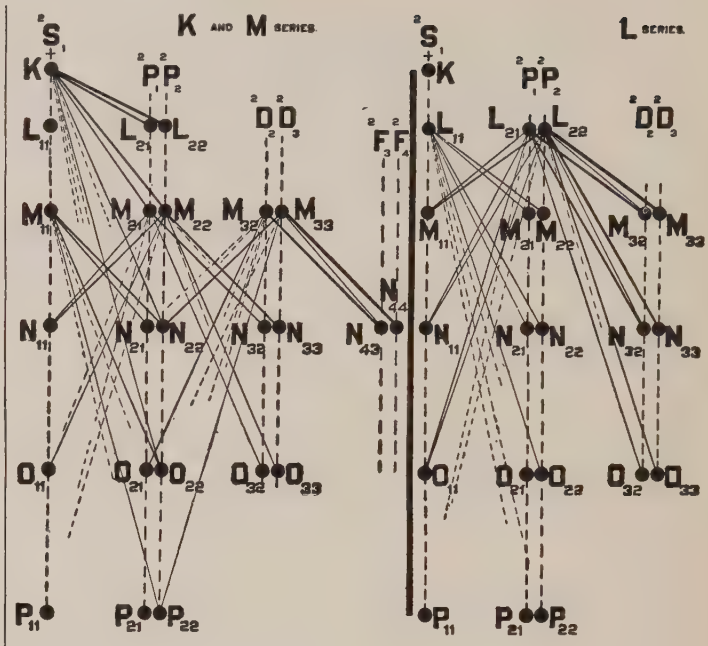

FIG. 2.—Transitions involved in emission of lines of the K-, L-, M-series.

Each type of electron orbit (arc of Fig. 1) is represented by a dot; its distance from the + above the K-dot represents the average radius of the orbit. In general, the electrons in the orbits corresponding to any horizontal row in the figure are bound more firmly than those in the row below; and those near the left end of a row, more firmly than those near the right. The symbol at the head of a column indicates the general type of energy level produced by ionization from an orbit of the type shown in that column (*see* Table 1). The sloping lines indicate the transitions which accord with the selection principles (p. 31), and their thicknesses indicate the relative intensities of the resulting spectral lines; if dotted and incomplete, the corresponding spectral line has not been observed, presumably because it is very weak or lies too near a strong line.

Regular Doublets.—In each spectrum a series of pairs of lines can be found such that $\Delta\nu$ is the same for each pair; *e.g.*, in the spectrum of W the following frequency differences are observed where $\nu_\infty = 3.29057 \times 10^{15}$ sec^{-1}:

Lines	η-l	β_1-α_2	γ_5-β_6	γ_1-β_2	γ_6-β_5	L_{21}-L_{22}	$K(\alpha_1$-$\alpha_2)$
$\Delta\nu/\nu_\infty$	98.75	98.54	99.00	98.05	98.51	98.71	98.5
Level$_2$	M_{11}	M_{32}	N_{11}	N_{32}	O_{32}	Limit	K

Each pair can be traced from element to element by means of Moseley's law as applied to the individual lines. It is thus found that, except for certain significant irregularities[1] (*v.* Figs. 5, 6), $\Delta\lambda$ for any one pair is nearly the same for every element (*cf.* Fig. 7). Such pairs of lines are called *regular*, or *relativity*, doublets and are regarded as arising from the transfer of electrons between one common energy-level, $n(k, j)$, and one or other of two adjacent levels, $n'(k', j')$, $n'(k', j' + 1)$, belonging to another group and differing by one unit in j'. If the element is a constituent of a chemical compound, the value of $\Delta\lambda$ depends upon the nature of the compound; variations of nearly 10% may be so caused (*v.* Table 5).

[1] When the doublet-distance is abnormal, the lines of the doublet are more or less complex; *i.e.*, the system is really a multiplet.

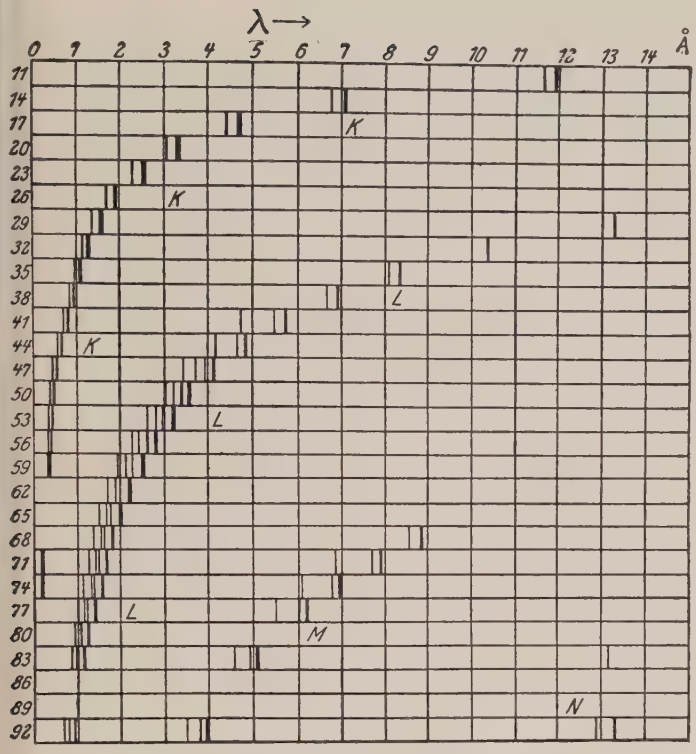

FIG. 3.—The strongest normal lines of the X-ray spectrum of every third element from $Z = 11$ to $Z = 92$. (*After Siegbahn* (142).)

Shows the relative positions of the several series and their changes from element to element.

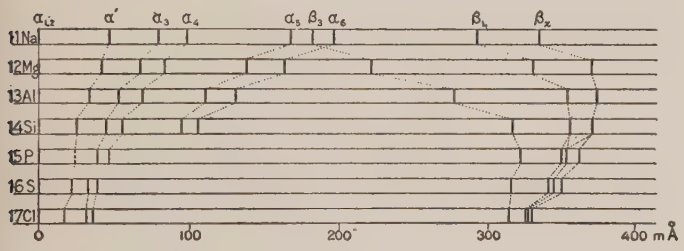

FIG 4.—Position of certain lines of the *K*-series with reference to $K\alpha_{1,2}$.

Numbers on the scale indicate $\Delta\lambda$ as measured from $K\alpha_{1,2}$. Note the anomalous position of the semioptical lines $K\beta_3$, $K\beta_1$, and $K\beta_2$ in 11Na, 12Mg, 13Al, and 14Si, which normally contain no electron in the M_{22}-orbit (*cf.* Fig. 1).

TABLE 5.—REGULAR DOUBLET SEPARATION: EFFECT OF CHEMICAL COMBINATION (133)

$\Delta\lambda$ = difference in the wave-lengths of the two components of the doublet K-L_{21}, K-L_{22} of element named in column (1). Unit of $\Delta\lambda = 0.001$ Å $= 10^{-11}$ cm.

1	Compound	Δλ	1	Compound	Δλ
Cl	KCl	3.15	Fe	Fe (powder)	4.20
	$BaCl_2$	3.15		$Fe(NH_4)_2(SO_4)_2$	4.13
	$KClO_3$	2.99		$FeNH_4(SO_4)_2$	4.01
	$Ba(ClO_3)_2$	2.98		$K_4Fe(CN)_6$	4.06
	$KClO_4$	2.92		$K_3Fe(CN)_6$	3.99
K	KCl	3.40	V	V(powder)	3.68
	$KClO_3$	3.22		NH_4VO_3	3.60
	$KClO_4$	3.16			

Irregular Doublets.—Another type of doublet, found in series limits, is characterized by the fact that $\Delta\sqrt{\nu}$ for a given doublet is nearly the same for every element (*see* Fig. 8, L_{11}, L_{21}; M_{11}, M_{21}; M_{22}, M_{32}; N_{11}, N_{21}; N_{22}, N_{32}; N_{33}, N_{43}; O_{11}, O_{21}; O_{22}, O_{32}; also *cf.* L_{11}- and L_{21}-limit, Table 4). These are called *irregular*, or *screening*, doublets and involve a pair of levels differing by one unit in k. Consequently, their appearance in lines is forbidden by the selection rule for k, and, when found, the forbidden line of the doublet is very faint.

Doublets of both types are found in the ultra-violet and the visible spectra of stripped atoms (122, 123).

Screening Numbers.—The frequency limit (ν_0) of the series $n(k, j)$ is related to Z and the quantum numbers as indicated (149) by eq. (1):

$$\frac{\nu_0}{\nu_\infty} = \frac{1}{n^2}(Z-S)^2 + \frac{\alpha^2}{n^4}(Z-s)^4\left(\frac{n}{j} - \frac{3}{4}\right) + \frac{\alpha^4}{n^6}(Z-s)^6\left[\frac{1}{4}\left(\frac{n}{j}\right)^3 + \frac{3}{4}\left(\frac{n}{j}\right)^2 - \frac{3}{2}\frac{n}{j} + \frac{5}{8}\right] + \ldots \quad (1)$$

where α^2 $(\equiv 2\pi e^2/hc\epsilon_0)^2 = 5.31 \times 10^{-5}$, ϵ_0 = dielectric constant of a vacuum, and S and s are empirical *screening numbers* which are derived (190) from data for doublets, and are to be interpreted as measures of the amount by which the external system of electrons reduces the intensity of the electrical field acting upon the returning electron. Excepting the K-level, for which there is only one value of j, the value of s for any level can be obtained from the observed value of $\Delta\nu$ for the corresponding regular doublets, by inserting in eq. (1) the two values of j and subtracting, it being known that $\Delta\nu_0 = \Delta\nu$. Knowing s, S is computed from ν_0 by means of eq. (1). It depends upon Z, is independent of j, but varies with k, and is, thus, associated with irregular doublets. It is found that the difference (ΔS) corresponding to the levels $n(i, i)$ and $n(i+1, i)$ is $\Delta S = 0.57n2^{i-1}$; probably ΔS is independent of Z; observed irregularities are only a few per cent and are believed to arise from errors.

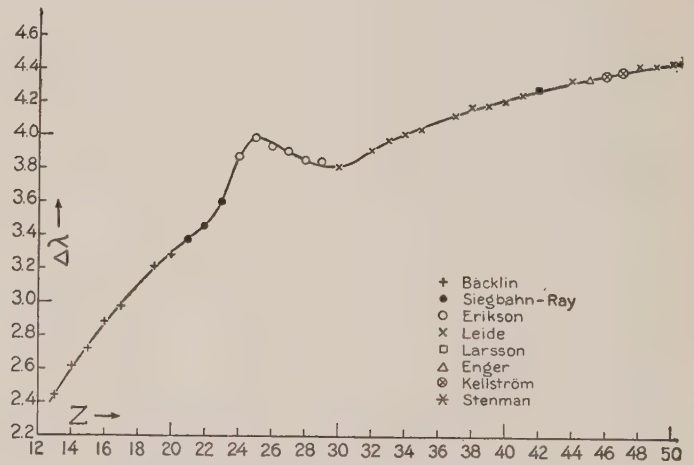

FIG. 5.—Irregularities in the separation of the components of the $K\alpha$ doublet (7, 78, 79, 96, 106, 109, 144).

$\Delta\lambda = \lambda_{K\alpha_2} - \lambda_{K\alpha_1}$; unit = 1 XU = 1mÅ $= 10^{-11}$ cm.

For values of S, *see* Fig. 9 or (190). For K-level, $s = S$; for $(L_{21,22})$, $s = 3.492 \pm 0.07$ if $41\text{Cb} \leq Z \leq 92\text{U}$ (149); for $[n(i, i-1), n(i, i)]$, $s = 4.23(n-2)i$ if $n > 2$, and is nearly independent of Z except for $n = 4$, $i = 4$, for which s decreases with Z (149). For certain irregularities, *see* Figs. 5, 6.

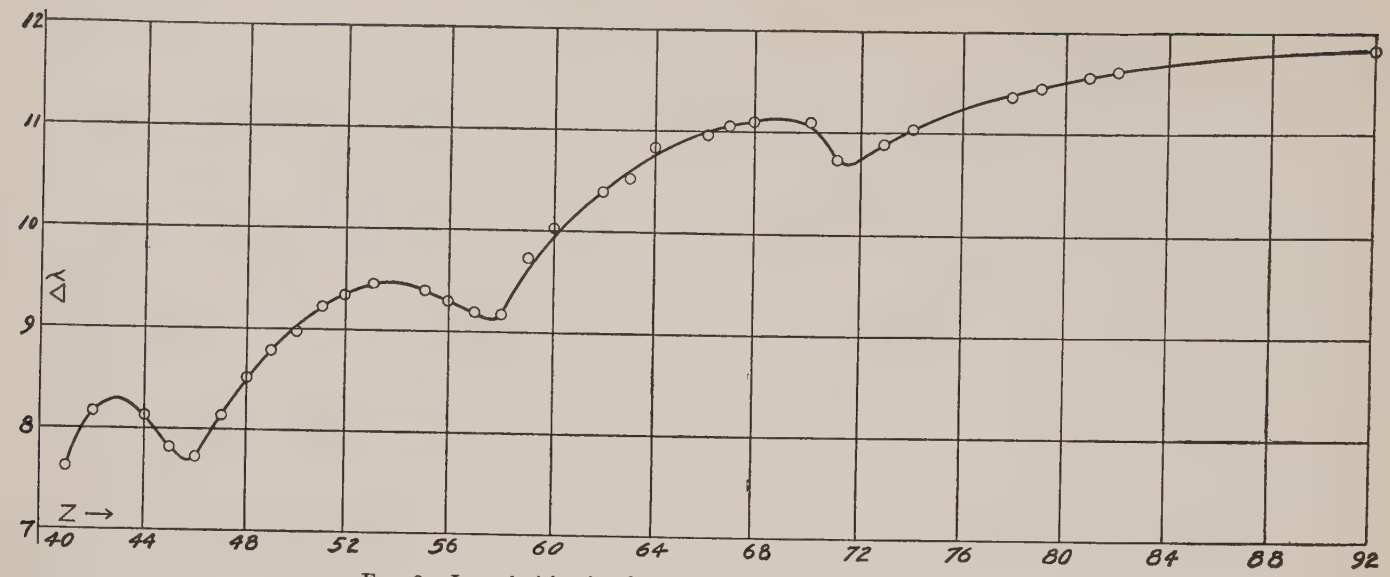

FIG. 6.—Irregularities in the separation of the $L\alpha$ doublet (132).
Unit of $\Delta\lambda$ = 1mA.

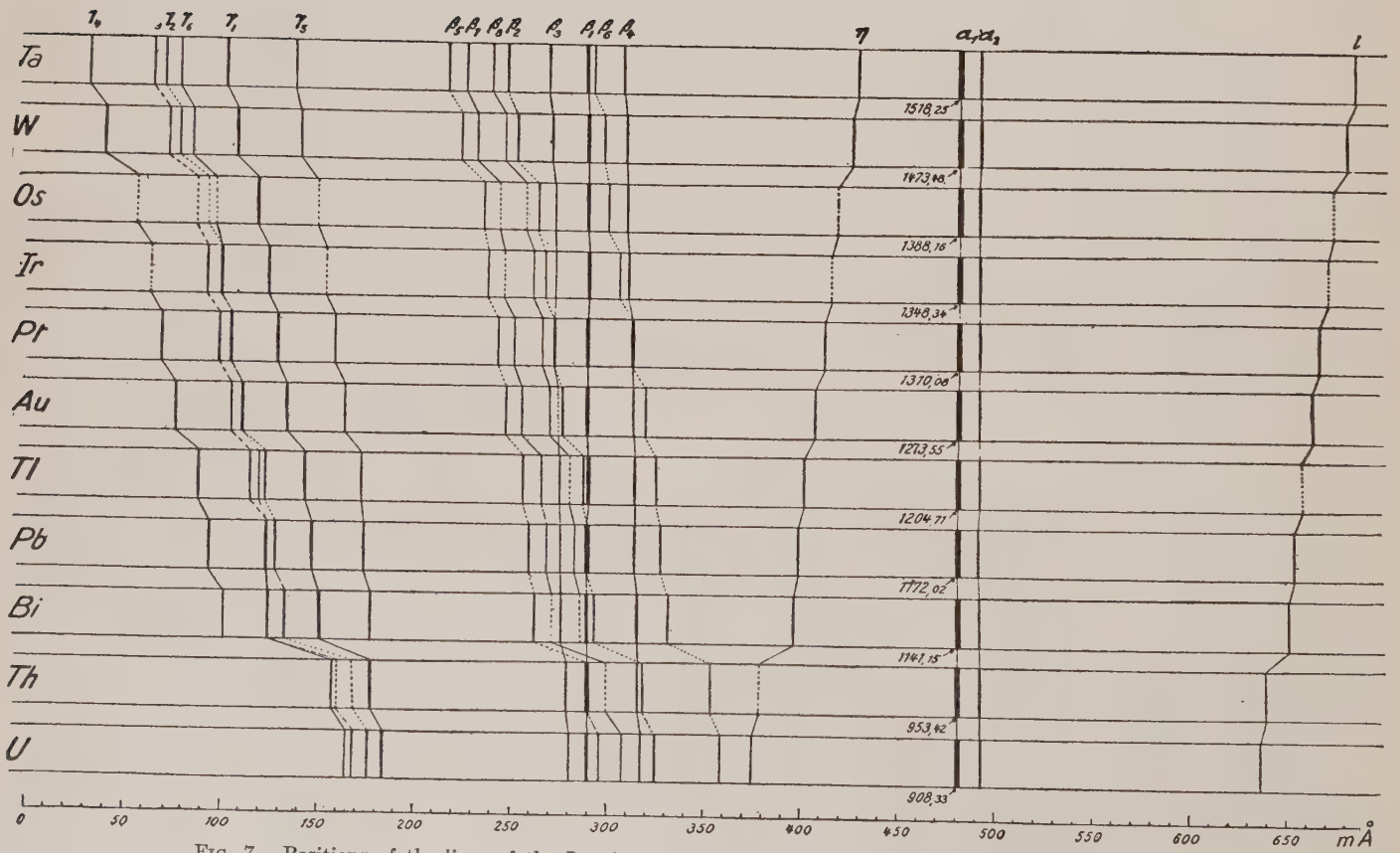

FIG. 7.—Positions of the lines of the L-series with reference to $L\alpha_1$. (*After Siegbahn* (142).)
For each element the actual wave-length of its $L\alpha_1$ is indicated. Unit of λ = 1mÅ = 10^{-11} cm.

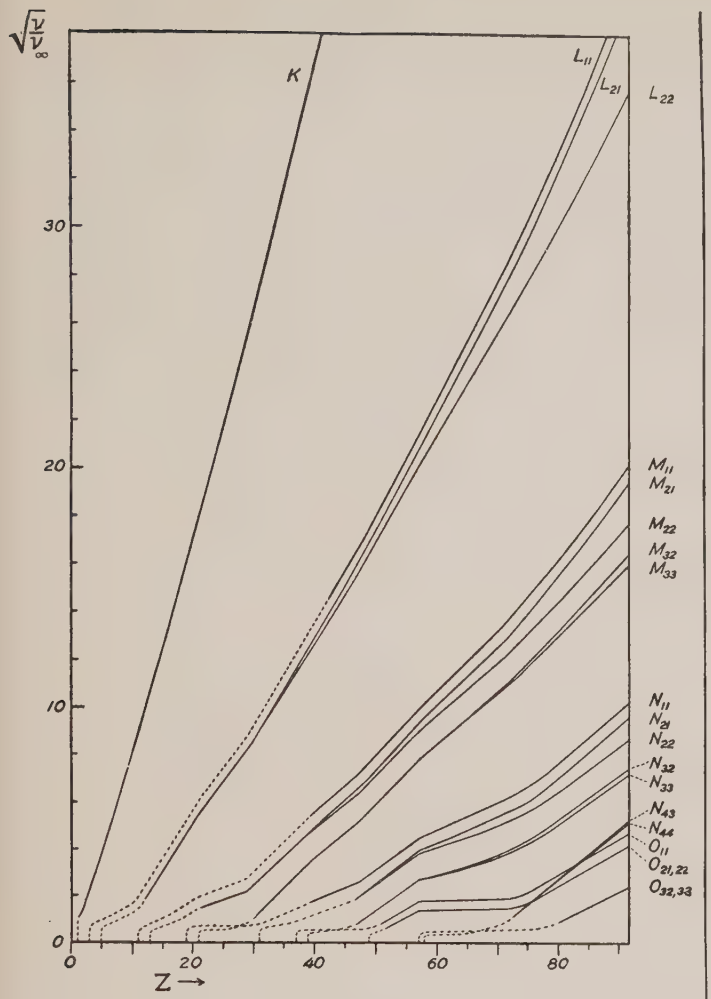

FIG. 8.—Bohr and Coster's Moseley diagram of the limits of the series. (*After Siegbahn* (142).)

The notation has been changed to that of Sommerfeld (*see* Table 1). $\nu_\infty = 3.29057 \times 10^{15}$ sec^{-1}. Nishina (127) gives a more detailed diagram of the *M*-, *N*-, and *O*-limits of elements 50 to 74.

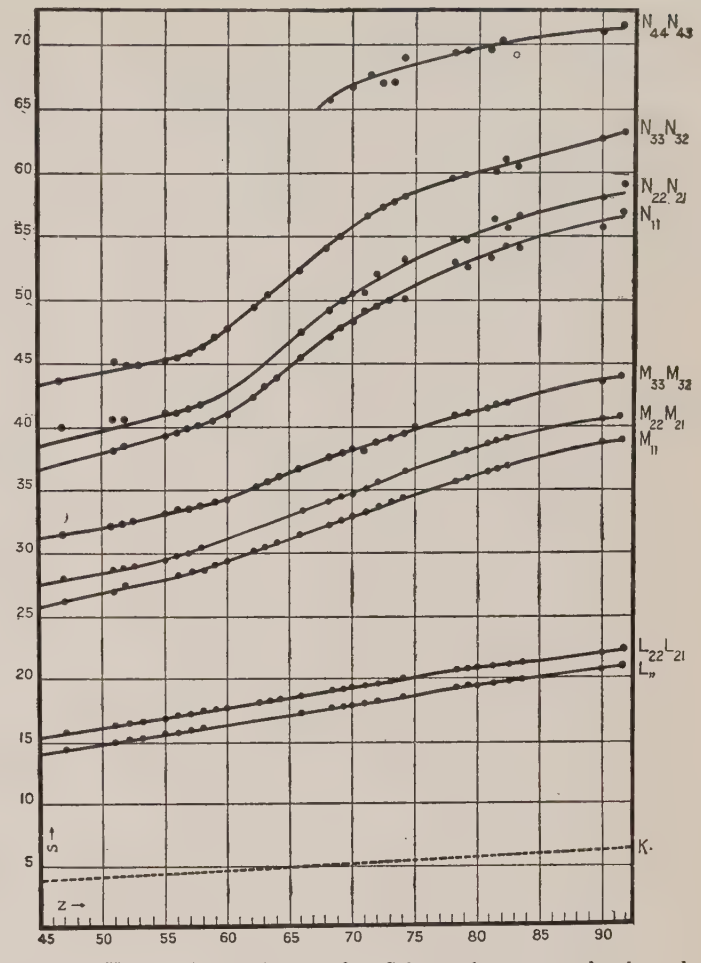

FIG. 9.—Values of screening number *S* for various energy-levels and atomic numbers (149); *cf.* p. 29.

Selection Principles.—It is observed that transitions corresponding to the stronger lines always occur in the direction $n(k, j)$ to $n'(k', j')$, where $n' = n - x$, $k' = k + y$; $j' = j + z$, and each of the quantities x, y, z has one of the "allowed" values indicated below.

	Allowed	
	Values	Examples
x	$+1, 2, 3 \ldots$	$M_{21} \rightarrow L_{11}$, $O_{11} \rightarrow L_{21}$
y	$-1, +1$	$M_{21} \rightarrow L_{11}$, $M_{11} \rightarrow L_{21}$
z	$-1, +1, 0$	$M_{32} \rightarrow L_{21}$, $N_{22} \rightarrow M_{33}$, $N_{21} \rightarrow L_{11}$

	Forbidden	
	Values	Examples
x	≤ 0	$L_{22} \rightarrow L_{11}$, $L_{22} \rightarrow M_{32}$
y	$0, \pm > 1$	$M_{22} \rightarrow L_{22}$, $O_{22} \rightarrow N_{43}$, $N_{43} \rightarrow M_{22}$
z	$\pm > 1$	$N_{21} \rightarrow M_{33}$, $M_{33} \rightarrow L_{21}$

With the exception of requiring that $x \neq 0$, these selection principles are identical with those of a normal doublet system in an optical series. They refer to probabilities, and consider nothing but the structure of the isolated atom. Whenever the atom contains no electron of a particular group (as *e.g.*, normal Cu contains no O_{11}-electron) the levels due to ionization from that group do not give rise to any line in its spectrum; if such electrons are present only in optically excited atoms, the lines are semi-optical and are abnormal in position, *cf.* Fig. 4.

The only possible violation of the total quantum selection principle ($x \neq 0$) which would give a line in the X-ray region is L_{11}-L_{22}. This line has been sought (35, 83) but not found, although in the optical region this transition corresponds to the strongest (red) line in the Li spectrum. Violations of the other selection principles (regarding x and y) are quite common (*see* Tables 3, 11), but it is reported (5) that no forbidden line of the *L*-series is so much as 0.001 as intense as L_{22}-M_{33}. All lines violating any of the selection principles are extremely weak and, in this section, are classed as non-diagram lines.

Intensities of Lines (*see also* Tables 2, 6).—*Variation with Energy-Level.*—For a given tube potential, the relative intensities of the lines are determined by the energy-levels involved and the probabilities (*P*) of the several transitions. In the preceding table, the allowed values of x, y, and z are arranged, in each case, in the order of decreasing values of P; the three sets may be regarded as mutually independent. Also, for given values of x, y, z, and n, the intensity increases with the values of j and of k.

For transitions of the type $n(k, j)$-$n'(k', j')$ where $k' = k + 1$, $j = k$ or $k - 1$, $j' = k$ or $k + 1$, and n and n' are two given positive

integers, the relative values of P are as follows [103, 149, 150], where i denotes the numerical value of k:

	Transition	$P(4i^2-1)$	Example	i	$P(4i^2-1)$
a	$n(i,i)$-$n'(i+1, i+1)$	$2i^2+i-1$	L_{22}-M_{33}	2	9
b	$n(i,i-1)$-$n'(i+1, i)$	$2i^2-i^*-1$	L_{21}-M_{32}	2	5
c	$n(i,i)$-$n'(i+1, i)$	1	L_{22}-M_{32}	2	1
d	$n(i,i-1)$-$n'(i+1, i+1)$	0	L_{21}-M_{33}	2	0

If the lines form a close doublet, their intensities (J) are essentially proportional to P.

For the special case of $i = 1$ (orbits of the $^2S_1$ type), only transitions *a* and *c* are possible and $P_a = 2P_c$; *e.g.*, $P(K\text{-}L_{22}) = 2P(K\text{-}L_{21})$. If $i = 2$, $P_a + P_c = 2(P_b + P_d)$ and $2(P_a + P_d) = 3(P_b + P_c)$. For confirmatory data, *see* [149].

Values of P for other types of transition have not yet been definitely determined, but a first approximation to a total quantum rule has been given [86].

Relative Intensities within a Given Subseries.—The ratio of the apparent intensities (I_ψ) of any two lines in the same subseries is independent of the tube potential [169, 174, 175, 184, 196]. Examples of its variation with Z are given in Table 6.

Table 6.—Relative Apparent Intensities (I_2/I_1) of Normal Lines of K-Series; Variation with Z

$(\beta_3 + \beta_1 + \beta_2 + \beta_4)/(\alpha_1 + \alpha_2)$

Z	Obs.*	Tube*	Targ.*	Lit.
24Cr	0.313	0.136	0.0810	[169]
29Cu	0.213	0.153	0.136	[169]
	0.165†			[147]
30Zn	0.193†			[147]
42Mo	0.251	0.180	0.175	[196]
	0.20†			[50]
45Rh	0.176	0.210	0.168	[169]
	0.158			[175]
46Pd	0.189	0.160	0.139	[196]
47Ag	0.167	0.215	0.207	[169]
	0.20†			[50]
74W	0.33			[68]

$I/I\alpha_1$

Z	α_2	$\beta_{3,1}$	β_2	Lit.
26Fe, 29Cu, 30Zn	0.50	0.26‡	$<<0.05$‡	[142, 147]
42Mo	0.50§	0.30§	0.05§	[50, 67, 196]
74W	0.50	0.35	0.15	[71]

For all of these, β_4 is very faint

* Obs. = observed, values depend upon instrumental equipment; Tube = values within tube, after correction for various losses by absorption, reflection, etc.; Targ. = values within target, *i.e.*, as emitted by atom. The Targ. values are far from accurate; recent work [185] indicates that the corrections for target absorption have usually been too great.

† By photographic photometry.

‡ Values may be seriously in error, but $\beta_{3,1}/\beta_2$ is probably correct within 2 or 3 %.

§ Data [50, 67] for α_2 and $\beta_{3,1}/\beta_2$ have been combined with data [196] for $(\beta_3 + \beta_1 + \beta_2 + \beta_4)/(\alpha_1 + \alpha_2)$. (*See* column Obs.) Values for $\beta_{3,1}$ and β_2 uncertain by $0.05\alpha_1$.

Variation with Tube Voltage.—The formulae that have been proposed for the variation of the line intensity with the tube voltage are listed in Table 7; formulae (1) and (2) are empirical; the others are theoretical, (5) having the best theoretical basis. In all five, I is defined for each line as the power radiated per unit solid angle and per electron in the cathode ray current. It is the product of three factors: The quantum $\mathbf{h}\nu$; the probability that an electron will cause the emission of such a quantum (this is very small, as very few of the electrons give rise to X-rays); and the fraction of the quanta that is not absorbed within the target. C_1 and C_2 are independent of V, but are functions of λ, of direction from the target surface, etc. C_3 and C_4 are constants for any one line. $K^2 \equiv \mu \csc \epsilon_x / b \csc \epsilon_c$, where μ is the absorption coefficient of the target for the X-rays considered, and b is its stopping power for the cathode rays ($v_x^2 = v_0^2 - bx$, v = velocity), ϵ_x and ϵ_c are the angles the X-rays and the cathode rays make with the surface of the target. N = number of such electrons per unit volume as are of the type required for the excitation of the line considered (*e.g.*, for a K-line, N = twice the number of atoms per unit volume); $T \equiv E/\mathbf{e}V_0$, where E = kinetic energy of the electron in its orbit; $U \equiv V/V_0$; u = probability that a removal of an electron of the proper type will actually result in an emission of a quantum of the line considered; V = tube voltage; V_0 = excitation potential; V_1 an empirically determined potential that exceeds V_0; ν = frequency; $\mathbf{e}$ and $\mathbf{h}$ have their usual significance.

Table 7.—Formulae for Variation of Line Intensity with Tube Voltage

For symbols and discussion of formulae, *see* adjacent text

No.	Formula	Lit.
(1)	$I = C_1(V - V_0)^n \quad V_0 < V < 2V_0$	[1, 92, 184]
(2)	$I = C_2(V^2 - V_1^2) \quad 1.5V_0 < V < 3V_0$	[97, 169, 196]
(3)	$I = C_3\left[\frac{1}{K^2}\left(1 - e^{-K^2(V^2-V_0^2)}\right) - \frac{2V_0}{K}e^{-K^2V^2}\int_{KV_0}^{KV} e^{y^2}\,dy\right]$	[53]
(4)	$I = C_4 e^{-K^2V^2}\left[\frac{1}{V}\int_{V_0}^{V} e^{-K^2y^2}\,dy - \int_{V_0}^{V}\frac{1}{y}e^{-K^2y^2}\,dy\right]$	[92]
(5)	$I = \frac{Ne^2uh\nu}{6b}\left[(U-1)(2T+3) - \frac{2T}{T+1}\log\left(\frac{U(T+2)}{U+T+1}\right)\right.$ $\left. - \{3 + (T+1)(2T+3)\}\log\left(\frac{U+T+1}{T+2}\right)\right]$	[160.1]

In formula (1), n is about 1.5 for rays subject to great absorption in target (emerging at small angles); for other rays, $n = 1.7$ to 2.1.

Formula (2) refers to rays subject to small absorption in target; V_1 is about $1.2V_0$ to $1.5V_0$, but is often misquoted as V_0.

It appears that in formula (3) the correction for absorption in target is several times too great unless $V - V_0$ is small [185]. If $K = 0$, this formula reduces [92] to $I = C_3(V - V_0)^2$, which is a special case of (1), but is often misquoted as $C_3(V^2 - V_0^2)$, and confused with (2). At times, K is treated as an arbitrary constant, its definition being ignored ([97]; *cf.* Fig. 11). For shape of graph defined by this equation, *see* Fig. 10.

In formula (4) also, the correction for absorption in the target is too great; K is frequently treated as an empirical constant. For graphs defined by (4), *see* [92]; they are much like those of Figs. 10 and 11.

Formula (5) is proposed for circular orbits only (K, L_{21}, L_{22}, M_{32}, M_{33}, N_{43}, N_{44}), and contains no correction for absorption in target. With an arbitrary unit of intensity, it fits the data [196] for K-series of Mo42 the best of all [160.1]; and data [182] for Ag47 indicate (though with large probable error) that it is good also for absolute intensity, but only for the directly produced rays (*see* p. 27), *i.e.*, for about 65 % of the rays of the K-series of Ag.

Ratio of Line Intensity to Intensity of Continuous Spectrum.—If I_l = intensity of the line (= power radiated per unit solid angle in the direction considered) and if $I_c d\lambda$ = power radiated per unit solid angle in the same direction by a strip of continuous spectrum of length $d\lambda$, then the ratio of the two intensities may be specified by $\Delta\lambda$ as defined by the equation $I_l = \int_{\lambda - \frac{1}{2}\Delta\lambda}^{\lambda + \frac{1}{2}\Delta\lambda} I_c d\lambda$, where λ is the wave-length of the line. In Figs. 12 and 13 the ordinates are proportional to $\Delta\lambda$. For illustrative values of $\Delta\lambda$, *see* Table 8.

TABLE 8.—RATIO OF LINE INTENSITY TO INTENSITY OF CONTINUOUS SPECTRUM

$I_l = \int_{\lambda-\frac{1}{2}\Delta\lambda}^{\lambda+\frac{1}{2}\Delta\lambda} I_c d\lambda$; λ = wave-length of line l; tabular values are $\Delta\lambda/\lambda$; probable error for Ag is 10%; for Cd, 5%; unit of V = 1000 volt = 1 kv.

Line	Rays \ V	35	50	65	80
Ag$K\alpha$ doublet	Direct	0.10	0.24	0.31	0.41
Ag$K\alpha$ doublet	Indirect	0.055	0.13	0.16	0.21
Ag$K\alpha$ doublet	Total	0.15	0.37	0.47	0.62
Cd$K\alpha$	Total	0.125	0.32	0.45	0.58
Cd K$\beta\gamma$	Total	0.034	0.075	0.10	0.13

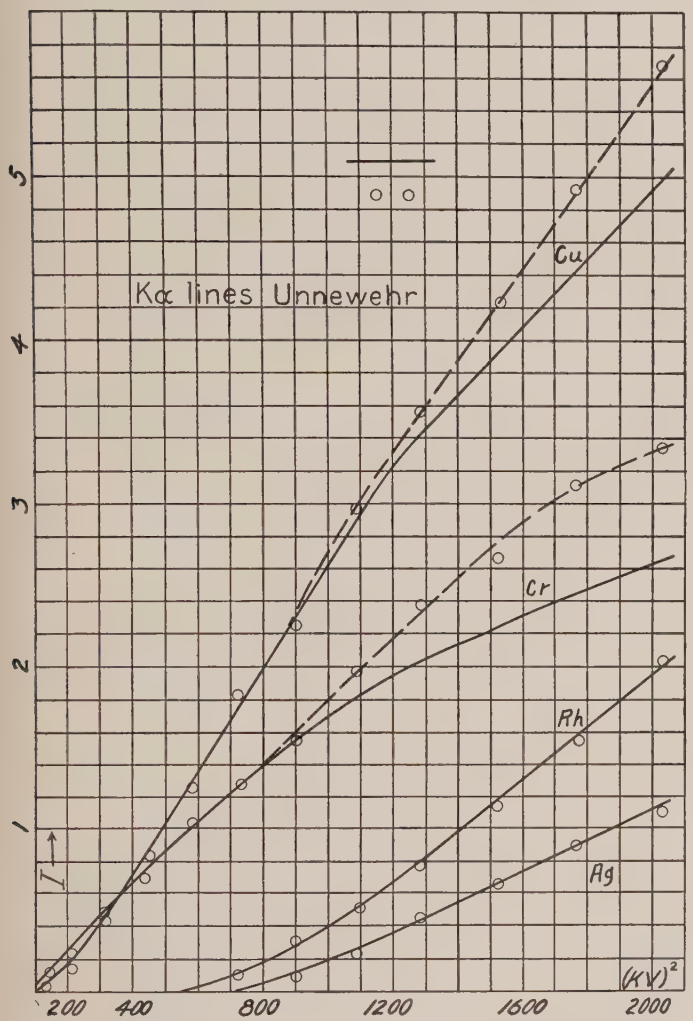

FIG. 10.—Intensities (I) of $K\alpha$ lines: Variation with potential (V) (169).

Solid lines represent Bergen Davis' equation (*see* p. 32). Unit of I is arbitrary; of V = 1000 volt; *cf.* Fig. 11.

TABLE 9.—PRIMARY STANDARDS OF WAVE-LENGTH*

All values are based upon Siegbahn's value (28, 140, 142) of (d_c) the grating space for calcite in the first order,† d_c = 3.02904 Å (or, more exactly, $\log_{10} 2d_c = 0.7823347$), or its equivalent value for rock salt, d_r = 2.81400 Å ($\log_{10} 2d_r = 0.7503541$); when necessary, the data have been recomputed; these are marked with an r. This value of d_c exceeds the I. C. T. value (Vol. I, p. 18) by 3.435 parts in 10 000. Only those data marked with a c have been corrected for refraction by the crystal (*cf.* (142)). For Lang's system of secondary standards based on $K\alpha_1$ for Cu as

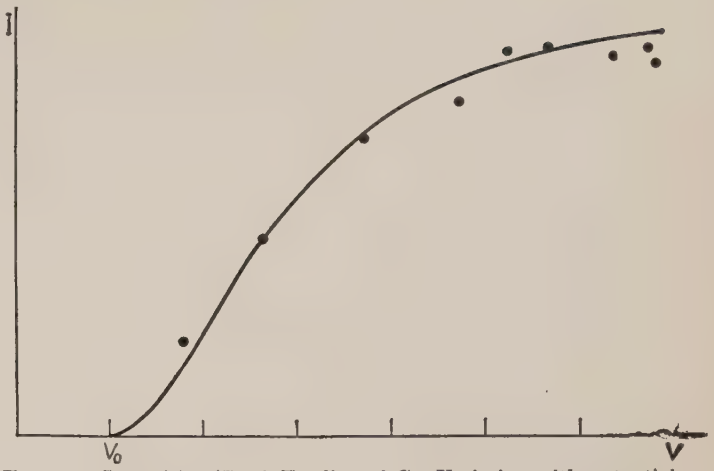

FIG. 11.—Intensities (I) of $K\alpha_1$ line of Cr: Variation with potential (V) (97).

Solid line represents Bergen Davis' equation (*see* p. 32) with K regarded as a constant to be determined from the observations; *cf.* Fig. 10.

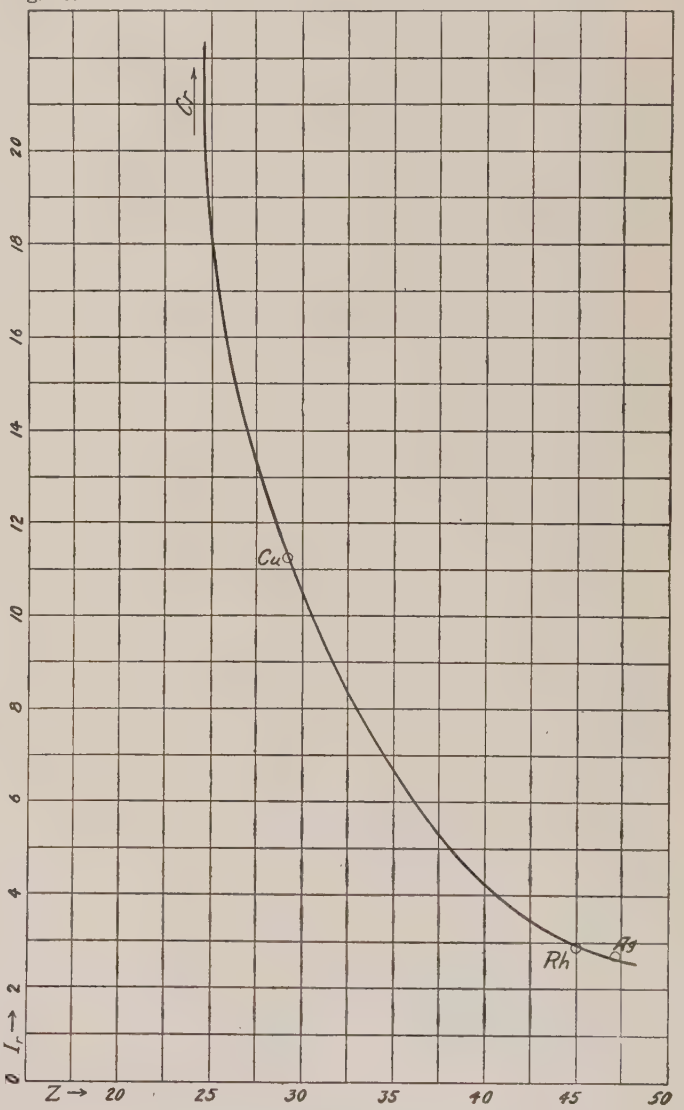

FIG. 13.—Ratio (I_r) of intensities of $K\alpha$ line to the same width of continuous spectrum in the same region: Variation with atomic number (Z) (169).

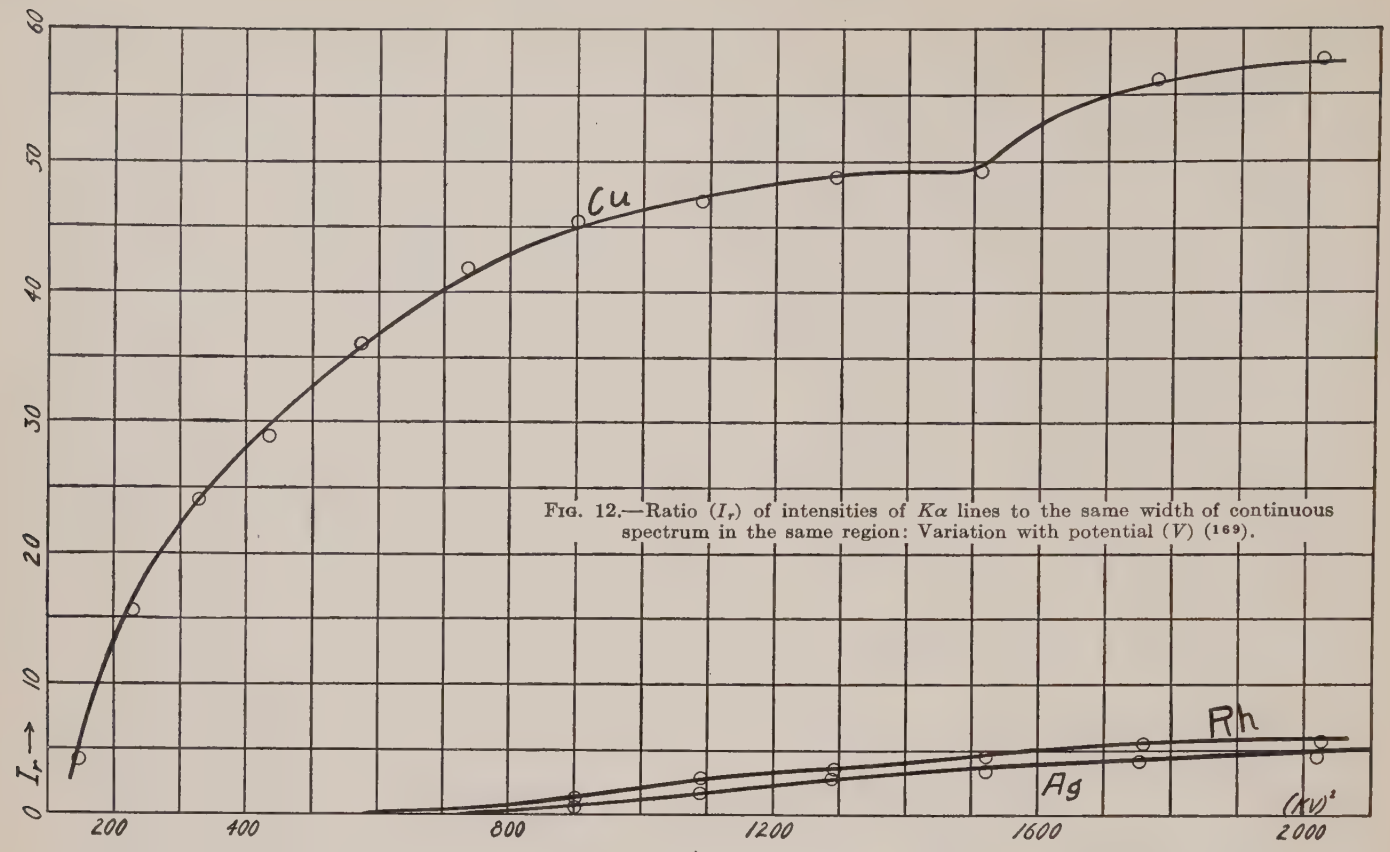

FIG. 12.—Ratio (I_r) of intensities of $K\alpha$ lines to the same width of continuous spectrum in the same region: Variation with potential (V) (169).

TABLE 9.—(*Continued*)

λ = 1537.30mÅ, *see* (105); his values for λ's of most prominent lines of 76Os, 77Ir, 78Pt, 79Au, 82Pb, and 83Bi average 0.48mÅ greater than Coster's (142).

Line = Siegbahn's notation, *see* Table 2; θ = observed glancing angle for maximum intensity; λ = wave-length; P. E. = probable error in λ; unit of λ = 1mÅ = 0.001 Å = 10^{-11} cm.

	Line	θ	Crystal	λ	P. E.	Lit.
26Fe	$K\alpha_2$	18° 38′ 13.2″	Calcite	1935.987		(106)
	$K\alpha_1$	18 35 52.3	Calcite	1932.066		(106)
29Cu	$K\alpha_1$	14 42 0.3	Calcite	1537.29	st‡	(108)
	$K\alpha_1$	16 31 31.5	Pyrite *r*	1537.75*c*	0.15	(125)
			Mean	*1537.52*		
	$K\beta_1$	14 53 39.0	Pyrite *r*	1389.63*c*	0.15	(125)
74W	$L\alpha_2$	14 11 0.0	Calcite	1484.38		(81)
	$L\alpha_1$	14 4 32.9	Calcite	1473.36		(81)
	$L\beta_1$	12 11 23.5	Calcite	1279.17		(81)
	$L\beta_2$	11 49 50.4	Calcite	1242.03		(81)
	$L\gamma_1$	10 25 33.5	Calcite	1096.30		(81)
35Br	*K*-limit		NaCl	918.6		(131)
	K-limit		Calcite *r*	918.2	§	(60)
			Mean	*918.4*		
	K-limit	8 43 0	Calcite	918.09		(109)
	D. R. $\frac{210}{100}$‖	8 7 48	NaCl	795.9	<0.1	(131)
42Mo	$K\alpha_2$		Calcite	712.105		(106)
	$K\alpha_2$		Calcite	712.175		(2)
	$K\alpha_1$	6 42 35.3	Calcite	707.831		(106)
	$K\alpha_1$		Calcite	707.865		(2)
	$K\beta_3$		Calcite	631.543		(106)
	$K\beta_3$		Calcite	631.657		(2)
	$K\beta_1$	5 58 42.5	Calcite	630.978		(106)
	$K\beta_1$		Calcite	631.094		(2)
	$K\beta_2$		Calcite	619.698		(106)
	$K\beta_2$		Calcite	619.823		(2)
47Ag	*K*-limit		NaCl	484.2		(131)
	K-limit		Calcite *r*	485.2	‡	(60)
			Mean	*484.7*		
	K-limit	4 35 24	Calcite	484.80		(109)
	D. R. $\frac{310}{100}$‖		NaCl	431.6	<0.1	(131)
74W	$K\alpha_2$		Calcite	213.52	**	(141)
			Calcite *r*	213.48¶	0.03	(71)

TABLE 9.—(*Continued*)

	Line	θ	Crystal	λ	P. E.	Lit.
74W	$K\alpha_2$		Calcite	213.69	0.08	(32)
			(?)	213.41	0.1	(135)
			Mean	*213.52*		
	$K\alpha_1$	1 58 27.6	Calcite	208.71	st§	(108)
		1 58 32.6	Calcite	208.85	**	(141)
			Calcite *r*	208.67¶	0.04	(71)
			Calcite	208.84	0.08	(32)
			(?)	208.50	0.1	(135)
			Mean	*208.71*		
	$K\beta_1, \beta_3$	1 44 38	Calcite	184.36	**	(141)
			Calcite *r*	184.26¶	0.03	(71)
			Calcite	184.56	0.08	(32)
			(?)	184.16	0.1	(135)
			Mean	*184.34*		
	$K\beta_2$	1 41 49	Calcite	179.40	**	(141)
			Calcite *r*	179.07¶	0.06	(71)
			Calcite	179.07	0.25	(32)
			(?)	179.00	0.1	(135)
			Mean	*179.13*		
	K-limit		Calcite *r*	178.12¶	0.07	(71)
			NaCl	178.02	††	(42)
			Mean	178.07		

* When it is not convenient to replace the X-ray tube by one of the elements here listed, the absorption limits of Br and of Ag are the most convenient standards. They always appear in photographically recorded spectra, and when ionization methods are used one of them may be introduced by using CH_3Br in the ionization chamber or by inserting Ag foil (0.005 to 0.01 cm thick (43)) into the path of the rays.

† Grating space of calcite in second order is 3.02935 Å ($\log_{10}$ = 0.4813494), in third order it is 3.02940 Å ($\log_{10}$ = 0.4813566).

‡ Mean value, individual values differ from mean by $\leq$ 0.05mÅ. Later measurements, not yet published, give systematically somewhat higher values. Hence, for the present, the Fe$K\alpha_1$ line is to be preferred as standard for the longer wave-lengths; the value here given for its wave-length was measured with the same instrument and crystal as the newest, most accurate measurements of (78, 79, 81, 96, 106, 188). "st" indicates that the data were used by Leide as standards. A newer, but unpublished, measurement of the Cu $K\alpha_1$ line with calcite crystal gives λ = 1537.39.

§ Settings estimated to 0.1 % of θ. ‖ Double reflection line. ¶ From spectra of high order. ** Mean values; individual values of θ differ from mean by *ca.*3.″

†† Based upon Siegbahn's values for K emission lines.

TABLE 10.—LIMITING FREQUENCIES (ν_0) OF X-RAY SERIES (17, 27, 40, 41, 127, 157, 162, 163)

In general, both emission and absorption data have been used in the calculation of the following values; they are more accurate than if they depended upon absorption alone.

If $\mathbf{h/e} = 1.37285 \times 10^{-17}$ erg sec es^{-1} (I. C. T. value, Vol. I, p. 17) and $\nu_\infty = 3.29057 \times 10^{15}$ sec^{-1} (not I. C. T. value), then the excitation potential is $V_0 = 13.546\ \nu_0/\nu_\infty$ absolute volt $= 13.5404\nu_0/\nu_\infty$ international volt (v)* ($\log_{10}$ 13.5461 = 1.1318141; $\log_{10}$ 13.5404 = 1.1316317). Tabular values are ν_0/ν_∞, where $\nu_\infty = 3.29057 \times 10^{15}$ sec^{-1}.

	K	L_{11}	L_{21}	L_{22}	M_{11}	M_{21}	M_{22}	M_{32}	M_{33}	N_{11}	N_{21}	N_{22}	N_{32}	N_{33}	N_{43}	N_{44}	O_{11}	O_{21}-O_{22}	O_{32}-O_{33}
92U	8477.0	1603.5	1543.1	1264.3	408.9	382.1	317.2	274.0	261.0	106.6	95.7	77.1	56.3	53.6	28.4	27.6	26.2	15.4	5.8
90Th	8073.5	1509.7	1451.5	1200.6	381.6	354.4	298.0	256.6	244.9	97.8			51.2	48.7	24.8	24.1			5.7
83Bi	6646.7	1207.9	1159.4	990.0	295.9	273.6	234.0	199.4	191.4	71.0	58.7	50.3	35.7	33.7	13.6	13.0		11.0	2.0
82Pb	6463.0	1169.3	1121.9	960.5	283.8	262.3	226.0	190.5	183.0	66.0	55.4	49.3	32.2	30.5	10.8	10.3	10.3	6.4	0.8
81Tl	6289.0	1132.4	1084.2	933.2	273.9	253.8	219.2	184.8	176.8	63.7	53.6	44.9	30.6	29.0	10.0	9.6	10.6	7.4	1.7
80Hg	6115.9	1094.6	1048.6	906.1															
79Au	5940.4	1060.2	1014.4	878.5	252.9	235.1	202.8	169.3	163.0	58.0	49.1	42.8	26.4	25.0	6.4		7.8	8.3	0.8
78Pt	5764.0	1026.8	978.7	852.0	243.4	227.3	198.0	162.3	156.4	52.5	48.7	42.3	24.5	23.2	5.2		7.1	8.6	0.4
74W	5113.8	893.0	850.6	752.1	208.1	191.3	169.8	138.3	133.7	44.1	38.0	33.0	18.8	18.4	2.9	2.8	5.7	5.2	(0)
73Ta		862.2	820.8	728.0	199.5	183.2	162.9	132.2	127.8	41.2	35.3	30.9	17.8	16.6	2.2	1.9	4.7	4.4	
72Hf		832.0	791.3	704.5	191.8	175.9	156.9	126.6	122.6	40.0	34.0	29.8	16.8	16.0	1.6	1.4	4.8	4.3	
71Lu		802.6	762.9	681.2	183.8	168.6	150.9	120.9	117.2	36.9	32.5	28.7	16.1	14.7	1.0	0.7	4.2	4.0	
70Yb		774.6	735.4	659.2	177.1	162.2	145.8	116.4	112.8	36.2	31.0	27.5	14.9	14.2	0.9	0.6		3.6	
69Tm		746.8	708.8	637.3	170.3	155.5	140.2	111.7	108.4	34.4	30.0	26.6	14.5	13.2	0.9	0.4		3.8	
68Er		719.6	682.6	615.9	163.6	148.8	134.7	107.2	104.0	33.1	28.4	24.9	13.7	12.6	0.9	0.3	3.9	3.9	
67Ho	4115.9	693.2	657.1	594.7	157.1	142.7	129.3	102.7	99.8	31.8	26.9	23.8	12.8	12.0	0.8	0.2		2.7	
66Ds	3972.5	667.7	632.2	574.2	151.2	136.9	124.5	98.5	95.8	31.0	26.1	23.2	12.2	11.6	0.8		3.1	3.2	
65Tb		642.6	608.3	553.9	145.0	131.0	119.6	94.2	91.6	29.4	24.3	22.0	11.4	11.1			3.5	2.6	
64Gd	3711.9	618.2	584.6	533.9	139.0	125.5	115.0	90.0	87.7	28.6	23.0	21.0	11.0	10.8			4.0	3.3	
63Eu	3583.4	594.3	561.5	514.4	133.1	120.2	110.3	86.0	83.8	27.2	22.6	20.4	10.7	10.4			3.6	2.9	
62Sm	3457.0	571.2	538.9	495.0	127.2	114.7	105.8	81.9	79.9	25.9	20.9	19.5	10.07	9.40			3.1	2.53	
60Nd	3214.2	526.2	495.5	457.8	116.5	104.8	96.8	74.2	72.5	23.7	19.2	17.8	9.28	9.08			3.1	2.67	
59Pr	3093.3	504.3	474.6	439.6	111.6	99.3	92.4	70.3	68.9	22.7	18.3	16.9	9.01	8.83			3.1	2.55	
58Ce†	2972.2	483.3	454.1	421.9	106.2	94.6	88.1	66.7	65.4	21.7	17.4	16.2	8.51	8.36			3.2	2.41	
57La†		462.9	434.2	404.4	100.7	90.0	84.0	62.9	61.7	20.5	16.5	15.4	8.08	7.83			3.0	2.34	
56Ba†	2756.4	441.9	414.3	386.7	95.4	84.6	79.0	58.8	57.6	18.8	14.9	14.0	7.09	6.70			3.1	1.56	
55Cs†	2649.1	421.8	394.9	369.3	89.8	79.3	74.4	54.6	53.6	17.1	13.6	12.6	6.04	5.73			1.9	1.08	
53I†	2448.3	382.6	357.6	336.0	79.2	69.1	64.8	46.8	45.9	14.0	9.4		4.16	3.91				0.38	
52Te†	2345.0	364.1	340.3	320.1	74.5	64.4	60.5	43.3	42.4	12.7	8.9		3.42	3.39				0.26	
51Sb†	2241.7	346.1	323.6	304.7	69.8	60.0	56.4	39.8	39.1	11.5	8.0		2.61	2.61			0.8	0.25	
50Sn†		329.4	306.3	289.5	65.3	56.2	53.1	36.5	35.9	10.2	7.4		2.0				0.2	0.6	
49In†	2057.2	312.0	289.3	274.0	60.1	51.8	48.8	32.4	31.9	8.2	5.5	5.2	0.7						
48Cd†	1967.6	296.8	274.3	260.7	56.9	48.7	46.2	30.4	29.9	8.1	5.6		0.4						
47Ag†	1878.9	280.9	259.9	246.8	52.8	44.8	42.6	27.4	27.0	6.9	4.7		0.2						
46Pd†	1794.0	267.1	245.7	234.1	49.7	42.9	40.7	25.4	25.0	6.7	5.3	5.0	0.3						
45Rh†	1709.1	251.7	231.8	221.3	46.3	38.8	37.0	23.0	22.6	6.0	4.2		0.1						
44Ru†			218.8	209.1	43.0			21.0	20.7	5.6			0.4						
42Mo†	1473.1	212.4	193.4	185.8	37.3	31.6	30.3	17.1	16.9	4.7	3.8		0.3						
41Cb†	1401.3	199.3	181.7	174.8	34.8	28.4	27.3	15.4	15.3	4.4	3.2								
40Zr†	1325.8	187.6	169.8	163.9	31.8	26.3	25.4	13.4		3.8	3.1								
39Yt†		174.5	158.8	153.3	29.2	22.8	22.0	11.7		3.5	1.6								
38Sr†		163.6	147.9	143.2	26.7	21.0	20.2	10.2		3.2	1.9								
37Rb†		152.3	137.6	133.2	24.1	18.2	17.6	8.4		2.4	1.3								
35Br†	992.57		117.69	114.29	18.99	13.50		5.19			0.2								
34Se†	932.02		108.37	105.40	16.68	11.57		3.80			0.2								
33As†	874.01		100.02	97.42	14.92	10.36		3.02			0.2								
30Zn†	711.73	87.2	77.10	75.39	10.10	6.80		0.84											
29Cu†	661.59	80.3	70.32	68.84	8.83	5.68		0.76											
28Ni†	614.12	73.8	64.70	63.37	8.28	5.40		0.67											
27Co†	568.24	67.7	59.04	57.80	7.72	4.73		0.60											
26Fe†	524.00	61.9	53.44	52.40	7.07	4.17		0.60											
25Mn†	481.83	56.3	48.18	47.34	6.2	3.70		0.34											
24Cr†	441.23	51.0	43.12	42.40	5.9	3.61		0.10											
23V†	402.7	45.9	38.5	38.0		3.0													
22Ti†	365.8	41.0	34.0	33.6		2.6													
21Sc	331.2		30.3	30.0		2.7													
20Ca	297.5		25.9	25.6		2.0													
19K	265.3		21.4	21.2		0.9													
17Cl	207.8		14.8	14.7		0.4													
16S	181.8		11.8			0.3													
15P	158.3		9.9			0.8													
13Al	114.7		5.2			0													
12Mg	95.8		3.5																

* Based on Weston normal cell = 1.018300 international volt at 20°C.

† These values are from recent data (40, 157, 163).

TABLE 11.—CHARACTERISTIC X-RAY EMISSION SPECTRA AND ABSORPTION LIMITS: ELEMENTARY SUBSTANCES

Substances which are mutually isotopic seem to have identical spectra (29, 70, 145); *see also* 82Pb in this table.

In each group of elements, the lines are arranged, as well as may be, in the order of decreasing wave-length (λ); the wave-lengths of those lines which are out of place, with reference to this order, are in italics. An "*x*" indicates that the line probably occurs, but coincides with another line. Except as otherwise indicated, the line notation is Siegbahn's and the difference notation is Sommerfeld's (Table 2).

The wave-lengths of at least some of the lines of the lighter elements are influenced by the valence of the element and are modified by the nature of the element with which it is combined and by the material of the anticathode upon which it is spread. Final data are not available; for preliminary work, *see* (113, 116, 117). For effect of chemical combination upon absorption limits *see* Table 12.

For relations connecting related lines, *see* p. 27; for methods for determining the subseries to which a line belongs, *see* (17, 142, 149, 183, 184). The excitation potential ($V_0 = h\nu_0/e = hc/e\lambda_0$) may be computed from the subseries absorption limit (λ_0): $V_0\lambda_0$ = 12 344 volt Å (absolute) = 12 339 Int. volt Å, if **h**, **c**, and **e** have the I. C. T. accepted values (Vol. I, p. 17) ($\log_{10}$ 12 339 = 4.09128).

(Literature references are given at the beginning of each section of the table, and at the end of the table are notes regarding the precision of the data, recomputations, etc., *see* p. 43.)

Tabular values are λ, unit = 1mÅ = 0.001 Å = 10^{-11} cm.

A. Sources.—Absorption limit: 12Mg, 13Al, and 18A (72, 80); others (114). Emission: Non-diagram lines (α' to β_x) of 11Na, 12Mg, and 13Al (193, 194), all relative to $\alpha_{1,2}$; β_1 to β_x of 14Si (8), of 15P (120), of 16S (116), of 17Cl (117); $\Delta\lambda_{\alpha_{2-1}}$ (7); others (142).

	Lines	5B	6C	8O	9F	Lit.	Grating
$\alpha_{1,2}$	K-$L_{21,22}$			23730	18300	(162, 163)	Crystal
$\alpha_{1,2}$	K-$L_{21,22}$		45500	24800		(51)	Crystal
$\alpha_{1,2}$	K-$L_{21,22}$		43960			(128)	Ruled
$\alpha_{1,2}$	K-$L_{21,22}$		45800			(89)	Ruled
$\alpha_{1,2}$	K-$L_{21,22}$		44900	23800		(160)	Ruled

	Lines	11Na	12Mg*	13Al*†	14Si*	15P‡	16S	17Cl	18A
α_2	K-L_{21}	11883.6	9867.75	8319.40	7109.17	6141.71	5363.75	4721.36	
α_1	K-L_{22}						5360.90	4718.21	
α_2-α_1	$\Delta\lambda_{\alpha_{2-1}}$			2.44	2.61	2.72	2.88	2.97	
α'§		11836.3	9825.3	8285.2	7083	*x*	5340.6	4702.5‖	
α_3§		11803.9	9800.0	8265.8	7063.8	6102.2	5329.37	4688‖	
α_4§		11785.9	9784.2	8250.1	7053.7	6095.0	5323.25	4684‖	
α_5§		11717.7	9729.4	8208.8	7014		5262.6(?)		
α_6§		*11687.1*	9704.4	8188.6	7003				
β_3§		11702	9647	8042	6793.3	5820.4¶	5047¶	4406.0‖	
β_1**		11592	9538	7965	6754.5	5792.1	5021.8	4394.2††	
β_{1x}**						5788.2	5017.*6*	4393.3	
β_x**		11550	*9499*	*7944*	6739.3	5779.6	5013.5	*4390.6*††	
	K-limit		9511.2	7947.0	6731.0	5767.4	5008.8‡‡	4393.8‡‡	3865.7

* For 12Mg, 13Al, and 14Si, Wentzel (192) points out the following relations between values of $\Delta\nu$: $(\alpha_6 - \alpha_4)_z = (\alpha_3 - \alpha_{1,2})_{z+1}$; $(\alpha_3 - \alpha_{1,2})_z < (\alpha_5 - \alpha_3)_z < (\alpha_3 - \alpha_{1,2})_{z+1}$.

† For 13Al, lines α_3 and α_4 appear (6) to have nearly equal intensities if V_T = 2.90 kv; hence, nearly equal values of V_0, both <2.9 kv; for K-limit V_0 = 1.55 kv. At V_T = 3.10, α', α_5, and α_6 are present; if they arise from double ionization, both electrons must be removed simultaneously and by the same cathode particle (36).

‡ Normal lines refer to red P. For P on Al, $\lambda\beta_{1x}$ = 5785.4 for red P and 5784.5 for black P.

§ Non-diagram line. Measured by Hjalmar except as otherwise indicated.

‖ Measured by Dolejsek. For 17Cl he also lists α'', λ = 4712.

¶ For β_3, Dolejsek gives λ = 4406.0 for 15P, λ = 5044.7 for 16S.

** For 15P, 16S, and 17Cl, $\lambda\beta_1$ and $\lambda\beta_x$ are average values for various chemical compounds that give both lines, $\lambda\beta_{1x}$ is the average value for those compounds that give only one line. For 11Na, 12Mg, 13Al, and 14Si, $\lambda\beta_x$ is for the pure element, $\lambda\beta_1$ is for oxide or other compound.

†† For $CaCl_2$, $\lambda\beta_1$ = 4394.7, $\lambda\beta_x$ = 4388.4.

‡‡ Hjalmar lists for 16S β_2(?), λ = 5012.7; and for 17Clβ'', λ = 4390.8.

B. Sources.—Absorption limits: 21Sc (72, 80), 27Co and 28Ni (60), others (114). Emission: K-series β_2 of 19K, 20Ca, 21Sc, 24Cr- and 25Mn; α_1, α_2, and β_1 of 24Cr and 25Mn; all except β''', of 26Fe, 27Co, and 28Ni (79); *cf.* (58); all β'' and β''' (58); others (142). L, series 19K and 20Ca (7), others (165).

	Lines	19K	20Ca	21Sc	22Ti	23V	24Cr	25Mn
$\alpha_{1,2}$	L_{22}-$M_{32,33}$					24200	21530	19390
β_1	L_{21}-M_{32}						21190	19040
α_2	K-L_{21}	3737.06	3354.95	3028.40	2746.81	2502.13	2288.907	2101.489
α_1	K-L_{22}	3733.68	3351.69	3025.03	2743.17	2498.35	2285.033	2097.506
α_2-α_1	$\Delta\lambda_{\alpha_{2-1}}$	3.21	3.28					
α''*		3730	3349	3023				
α_3*		3711.0	3332.3	3006	2726.9	2484.6	2273.3	2087.9
α_4*		3708.8†	3330.0					
β'*			3091.1	2799.2	2515.1§	2285.3§	2085.7	‖
β_1	K-$M_{21,22}$	3446.80‡	3083.43	2773.94	2508.98	2279.72	2080.586	1906.195
β''		3443.0‡	3079.7	2767.5	2500.7	2272.6		
β_2	K-$N_{21,22}$	3434.6	3069.1	2758.0	2493.7	2264.6	2066.71	1893.27
β'''		*3400.7*	*3044.3*	*2742.5*	*2483.6*	*2257.7*	*2061.7*	*1888.8*
	K-limit	3431.0	3064.3	2751.7	2491.2	2263.0	2066.3	1892.1

TABLE 11*B*.—(*Continued*)

Lines		26Fe¶	27Co	28Ni	Lines		26Fe¶	27Co	28Ni
l	L_{22}-M_{11}	2012o	1820o	1655o	$\alpha_{3,4}$*		1923.3	1777.4	1647.6
η	L_{21}-M_{11}	1965o	1777o	1617o	β_3		1756.46	1620.11	1499.10
$\alpha_{1,2}$	L_{22}-$M_{32,33}$	1758o	1594o	14528	β_1	K-$M_{21,22}$	1753.013	1617.436	1497.045
β_1	L_{21}-M_{32}	1722o	1562o	14235	β_2	K-$N_{21,22}$	1740.80	1605.62	1485.61
$\beta_{3,4}$	L_{11}-$M_{21,22}$	1561o		1314o	β'''		*1737.1*		
α_2	K-L_{21}	1936.012	1789.187	1658.353		K-limit	1740.5	1602.3	1489.5
α_1	K-L_{22}	1932.076	1785.287	1654.503					

* Non-diagram lines. Measured by Dolejsek, unless otherwise indicated.
† Hjalmar also lists for 19K, $\lambda\alpha' = 3718.7$, $\lambda\alpha_{3,4} = 3708.83$.
‡ Lundquist (120) finds for 19K, $K\beta_1 = 3446.99$, $K\beta'' = 3443.09$.
§ Non-diagram lines. Measured by Hjalmar.
‖ For 25Mn, $\lambda\beta_3 = 1910.50$ (79).
¶ The $K\alpha$-lines of Fe are unresolved multiplets.

C. Sources.—Absorption limit: 36Kr (23); others (60). Emission: K-series of 31Ga (167); $K\alpha_2$, $K\beta_2$, and $K\alpha_{3,4}$ of 29Cu, and $K\alpha_{3,4}$ of 30Zn (142); others of K-series (105, 108, 109); L-series (165).

Lines		29Cu	30Zn	31Ga	32Ge	33As	34Se	35Br	36Kr
l	L_{22}-M_{11}	1519o	1395o	1289o	11920	11047	10271	9563	
η	L_{21}-M_{11}	1483o	1361o	1256o	11585	10710	9939	9234	
$\alpha_{1,2}$	L_{22}-$M_{32,33}$	13308	12224	11270	10414	9650	8971	8357	
α'		1324o	12191	11238	10378	9616	8939	8326	
α''		13172	12150	11196	10341	9581	8903	8297	
β_1	L_{21}-M_{32}	13029	11958	11006	10152	9394	8717	8108	
β'		1299o	11934	10986	10131	9372	8698	8086	
β''		1296o	11893	10951	10102	9346	8671	8065	
$\beta_{3,4}$	L_{11}-$M_{21,22}$	1210o	1116o			8911			
α_2	K-L_{21}	1541.26	1435.87	1340.87	1255.21	1177.40	1106.43	1041.60	
α_1	K-L_{22}	1537.39	1432.06	1337.14	1251.30	1173.43	1102.42	1037.56	
$\alpha_{3,4}$†		1530.7	1428.8						
$\beta_{3,1}$	K-$M_{21,22}$	1389.27	1292.60	1205.20	1126.74	1055.18	990.25	930.84	
β_2	K-$N_{21,22}$	*1378.0*	*1280.97*		*1114.62*	*1042.93*	*997.90*	918.26	
	K-limit	1379.0	1296.7	1190.6	1115.0	1043.8	979.3	918.2	864.8

* Also 11224. † Non-diagram lines. Measured by Dolejsek.

D. Sources.—Absorption limit: K-series (60), L-series (73). Emission: K-series 42Mo (106), 45Rh (78), 46Pd (except β_4) (96), others (105, 108); L-series β_2', β_2'', γ_1', and $\gamma_{2,3}'$ (79), others (142).

Lines		37Rb	38Sr	39Yt	40Zr	41Cb	42Mo*	44Ru	45Rh
l	L_{22}-M_{11}		7821		6898	6509			5207.0
η	L_{21}-M_{11}	8029.0	7505		6593.1	6195	5835		4911.2
α_2	L_{22}-M_{32}					5717	5400	4843.67	4595.56
α_1	L_{22}-M_{33}	7302.7	6847.8	6434.9	6055.9	5711.3	5394.3	4835.67	4587.78
α_3†		7272.7	6818.3	6406.5	6027.2	5688.6	5372.1	4818	4572
β_1	L_{21}-M_{32}	7060.4	6609.2	6198.4	5822.2	5479.6	5165.8	4611.00	4364.00
β_6	L_{22}-N_{11}	6967.5	6503.0		5693.5	5346.1		*4476.4*	*4230.1*
β_4	L_{11}-M_{21}	6802.8	6385.5	6001.9	5652.7	5331.4	5035.8	4512.6	4277.8
β_3	L_{11}-M_{22}	6769.9	6349.9	5967.8	5618.2	5295.9	5000.2	4476.4	4241.3
β_2	L_{22}-$N_{32,33}$				5573.4	5225.3	4909.2	4361.9	4122.1
	L_{22}-limit							4360.4	4121.2
β_2'† (β_{11})						5169	4862.6	4323.4	4087.8
β_2''† (β_{12})							4847.7	4309.0	4076.6
γ_5	L_{21}-N_{11}	6738.6	6278.8		5481.0		4819.0	4276.6	4035.2
γ_1	L_{21}-N_{32}				5373.0	5024.1	4711.1	4172.82	3935.7
γ_1'† (γ_7)	L_{21}-limit							4169.3	3934.0
						4967	4662	4128	3894
$\gamma_{2,3}$	L_{11}-$N_{21,22}$	6028.2	5629.4		4941.2	4639	4361.3	3887.9	3677.0
$\gamma_{2,3}'$†					4895	4597	4323		3647
	L_{11}-limit								3618.6
α_2	K-L_{21}	927.72	877.54	831.18	788.50	748.82	712.105‡	646.15	616.371
α_1	K-L_{22}	923.60	873.37	827.00	784.29	744.57	707.831‡	641.81	612.023
β_3	K-M_{21}	827.02	781.51	739.32	700.48	664.49	631.543	571.43	545.093
β_1	K-M_{22}						630.978‡		544.491

TABLE 11*D*.—(*Continued*)

Lines		37Rb	38Sr	39Yt	40Zr	41Cb	42Mo*	44Ru	45Rh
β_2	K-$N_{21,22}$	814.84	*769.17*	726.63	688.35	652.55	619.698	560.48	533.957
β_4	K-$O_{21,22}$						618.25		
	K-limit	814.6	769.9	725.7	687.4	650.5	618.2	558.6	533.2

Lines		46Pd	Lines		46Pd	Lines		46Pd
l	L_{22}-M_{11}	4939.6	β_2	L_{22}-$N_{32,33}$	3900.7		L_{11}-limit	3420.6
η	L_{21}-M_{11}	4650.2		L_{22}-limit	3900.5	α_2	K-L_{21}	588.632
α_2	L_{22}-M_{32}	4366.60	β_2'† (β_{11})		3868.8	α_1	K-L_{22}	584.266
α_1	L_{22}-M_{33}	4358.50	β_2''† (β_{12})		3857.4	β_3	K-M_{21}	520.093
α_3†		4344	γ_5	L_{21}-N_{11}	3811.6	β_1	K-M_{22}	519.474
β_1	L_{21}-M_{32}	4137.30	γ_1	L_{21}-N_{32}	3716.36	β_2	K-$N_{21,22}$	509.181
β_4	L_{11}-M_{21}	4062.3		L_{21}-limit	3715.2	β_4	K-$O_{21,22}$	507.90§
β_3	L_{11}-M_{22}	4025.7	γ_1'† (γ_7)		3678		K-limit	507.70
β_6	L_{22}-N_{11}	4007.0	$\gamma_{2,3}$	L_{11}-$N_{21,22}$	3480.9			

* For 42Mo, non-diagram line $L\alpha_3$ has 6 components, usually unresolved; none of them are present if $V = 3$ kv, but the three nearest to $L\alpha_1$ are present if $V = 4$ kv; the others appear only at higher voltages (143). The normal lines $L\alpha_1$ and $L\alpha_2$ are excited at $V = 2.9$ kv.

† Non-diagram lines listed by Siegbahn.

‡ For Mo, Davis and Purks (53.2) find satellites on the long-wave sides of α_2, α_1, and β_1 the separations being 0.096, 0.085, and 0.17mÅ, respectively; they call them α_2', α_1', and β_1'.

§ Of doubtful origin; value from (109).

E. Sources (except as otherwise indicated).—Absorption limit: *K*-limit, 54Xe (23), others (60); *L*-limit, 54Xe (110), others (27, 73). Emission: *K*-series, 47Ag (96), 53I (33), others (33, 96, 105, 108); *L*-series β_2' and β_2'' (79), others (142).

Lines		47Ag	48Cd	49In	50Sn	51Sb	52Te	53I	54Xe
l	L_{22}-M_{11}	4697.6	4471.3	4259.3	4063.3	3880.3	3710.1		
η	L_{21}-M_{11}	4410.1	4187.5	3976.1	3781.8	3599.6			
α_2	L_{22}-M_{32}	4153.82	3956.36	3772.42	3601.08	3440.75	3291.00	3150.87	
α_1	L_{22}-M_{33}	4145.64	3947.82	3763.67	3592.18	3431.77	3281.92	3141.66	
α_3*		4131.70	3933	3749.91					
β_1	L_{21}-M_{32}	3926.64	3730.08	3547.83	3377.92	3218.36	3069.97	2930.93	
β_4	L_{11}-M_{21}	3861.1	3674.25	3499.0	3336.3	3184.3	3040.0	2906	
β_3	L_{11}-M_{22}	3824.45	3636.42	3461.9	3298.9	3145.14	3001.3	2867	
β_6	L_{22}-N_{11}	3799.4	3607.3	3428.0	3262.2	3107.8	2964.4		
β_2	L_{22}-$N_{32,33}$	3693.83	3506.4	3331.2	3167.9	3016.6†	2876.1	2746.08	
β_7	L_{22}-O_{11}			3317	3149				
	L_{22}-limit	3690.8	3496.3	3315.5	3149.3	2990.7	2845.7	2713.9	2587.5‡
β_2'* (β_{11})		3663.5	3478.7	3304.0	3142.6	*2993.4*			
β_2''* (β_{12})		3653.6	3470.7	3295.9	3134.7	2985.8†			
β_{10}*		3630		3265.8	3114.4	2972.5			
β_9*		3620		3259.8	3108.1	2965.8			
γ_5	L_{21}-N_{11}	3607.3	3418.1	3241.8	3077.4	2925.6	2783.1		
γ_1	L_{21}-N_{32}	3514.85	3328.0	3155.29	2994.93	2845.07†	2706.47	2577.48	
	L_{21}-limit	3506.7	3319.0	3139.5	2972.3	2821.9	2679.3	2547.5	2425.3‡
γ_1'* (γ_7)		3480	3296	3125	2968.5				
$\gamma_{2,3}$	L_{11}-$N_{21,22}$	3299.7	3131.6	2973.6	2827.3	2688.9	2564.9		
$\gamma_{2,3}'$*		3270							
γ_4	L_{11}-$O_{21,22}$			2919.1	2771.3	2633.6	2505.7		
	L_{11}-limit	3247.4	3077.3	2919.4	2769.6	2631.7	2503.9	2383.9	2272.4‡
α_2	K-L_{21}	562.669	538.29	515.46	493.96	473.86	454.91	436.94	
α_1	K-L_{22}	558.277	533.86	511.03	489.48	469.31	450.37	432.43	
β_3	K-M_{21}	496.647	474.97	454.42	435.06	416.23	399.26	383.92	
β_1	K-M_{22}	496.009	474.29	453.72	434.40			383.15	
β_2	K-$N_{21,22}$	486.030	464.38	444.09	424.85	407.10	390.37	374.61	
	K-limit	485.2	463.4	443.6	424.3	406.6	389.7	373.8	538.8

* Non-diagram lines listed by Siegbahn (142).

† Dauvillier (5, 47) lists for 51Sb$\beta_2''\lambda$ = 3011.7, β_9(L_{11}-M_{32})λ = 2989. β_8(L_{11}-M_{33}) = 2985.5 (corresponding, respectively, to Siegbahn's β_8, β_{10}, β_9), and $\gamma_{10}\lambda$ = 2840.

‡ These *L*-limits show strong absorption lines like the electropositive elements and unlike I^- and Br^-; they lie on the extrapolated curve for Ag to I, but not on that from Cs to Nd (110).

TABLE 11.—(*Continued*)

F. Sources (except as otherwise noted).—Absorption limit: *K*-limits, 55Cs and 56Ba (60), others (24); *L*-limits, 55Cs L_{11} (118), 57La and 58Ce (41), others (127). Emission: *K*-series (32, 33); *cf.* (109); *L*-series, η56Sa, all β_5, all γ_6 (L_{21}-O_{32}), and $\gamma_4$63Eu (5, 48), others (142).

Lines		55Cs	56Ba	57La	58Ce	59Pr	60Nd	62Sa	63Eu
l	L_{22}-M_{11}		3128.7	3000		2778.1	2670.3	2477.0	2390.3
η	L_{21}-M_{11}	2983.3	2857.1	2734	2614.7	2507	2404.2	2214.5	
α_2	L_{22}-M_{32}	2895.60	2779.02	2668.93	2565.11	2467.63	2375.63	2205.68	2127.33
α_1	L_{22}-M_{33}	2886.10	2769.64	2659.68	2556.00	2457.70	2365.31	2195.01	2116.33
α_3*			2755.4†					2184.6	
β_{11}*	L_{11}-M_{11}		2631.5						
β_1	L_{21}-M_{32}	2677.84	2562.24	2453.30	2351.00	2253.90	2162.21	*1993.57*	*1916.31*
β_4	L_{11}-M_{21}	2660.5	2549.8	2443.8	2344.2	2250.1	2162.2	1996.4	1922.1
β_{13}*	L_{21}-M_{33}						2154.8	1987.6‡	1908.1‡
β_3	L_{11}-M_{22}	2622.93	2511.0	2405.3	2305.9	2212.4	2122.2	1958.0	1882.7
β_6	L_{22}-N_{11}	2587.5	2477.2	2373.9	2276.9	2185.9	2099.3	1942.2	1870.5
β_{14}§					2212.1‖	2122.0	2038.8‖	1885.1‖	1781.4‖
β_2	L_{22}-$N_{32,33}$	2506.4	2399.3†	2298.0	2204.1	2114.8	2031.4	1878.1	1808.2
$\beta_{11,12}$§		2483	2381.7						
β_9*	L_{11}-M_{32}	2381.3¶						1866.2¶	*1794.0*¶
β_{10}§				2285	2191.6	2102.5	2019.3	1865.7	1796
β_9§		*2473*	*2371.2*	2277	*2184.0*	2095.8	*2011.7*	*1858.1*	1788
β_8*	L_{11}-M_{33}		2375.5		2184.4		2013.8	1858.9	1786.0
β_7	L_{22}-O_{11}	2480	2375.6	2270	2176.3	2087.4	2004.3	1852.3	1784
β_5	L_{22}-$O_{32,33}$		2359.5		2164.0			1843.7	1773.4
	L_{22}-limit	2467.4	2356.8	2253.7	2159.7	2072.8	1990.7	1840.8	1771.7
β_{10}*			2351.1		2153.1			1834.0	1764.7
γ_5	L_{21}-N_{11}	2411.1	2302.3	2200.8	2105.6	2016.1	1931.3	1775.1	1705
γ_1'*					2051.1		*1879.3*	1728.7	*1658.9*
γ_9§					2051	1962.2	1880.4	1728.5	1659.3
γ_1	L_{21}-N_{32}	2342.52	2236.60†	2137.20	2044.33	1956.81	1873.83	1723.09	1654.3
γ_{10}*			2218.6		2028.8		1860.0	1711.3	1642.2
γ_8	L_{21}-O_{11}		2218		*2019*	*1932.2*			*1629*
γ_7§			2218		2029	1942.2	1859		*1644*
γ_6*	L_{21}-N_{43}		2211.2		2019.6		1851.4	1701.9	1633.4
γ_6	L_{21}-O_{32}		2201.6		2009.1		1842.6	1692.6	1624.1
	L_{21}-limit	2307.5	2199.3	2098.9	2006.7	1920.1	1839.1	1699.1	1622.8
γ_7'*			2143.8					1664.4	1598.6
γ_{10}§		2236.9	2140.2	2048.1	1962.3	1881.1			
γ_3'*			2134.2		1956.1			1656.0	*1591.9*
γ_2	L_{11}-N_{21}	2232.2	2134.0	2041.6	1955.9	1875.0	1797.4	1655.9	1593.9
γ_3	L_{11}-N_{22}	2227.0	2129.5	2036.5	1950.9	1869.9	1792.5	1651.7	1587.7
γ_9*	L_{11}-N_{33}		2098.9		1922.5			1626.1	1561.9
γ_4	L_{11}-$O_{21,22}$	2169.1	2071.5†	1978.7	1895.2	1815.3	1740.8	1603.3	1541.0
	L_{11}-limit	2160.5	2062.0	1968.9	1885.6	1807.1	1731.7	1595.4	1533.3
α_2	K-L_{21}	403.98	388.91	374.60	360.97	348.05	335.96	313.20	302.69
α_1	K-L_{22}	399.48	384.31	369.96	356.37	343.40	331.31	308.54	297.99
β_3	K-M_{21}	354.36	340.89	328.09	315.72	304.39	293.51	273.25	263.86
β_1	K-M_{22}	353.62	340.22	327.26	315.01	303.60	292.75	272.50	263.07
β_2	K-$N_{21,22}$	345.16	332.22	319.66	307.70	296.25	285.73	265.75	256.45
	K-limit	344.5	330.8	318.6	306.5	295.1	284.6	264.4	254.8

* Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's β_7 and β_7' are entered as β_7' and β_7, respectively. His β_2'', β_8, β_9 are, respectively, the same as Siegbahn's β_8, β_9, β_{10}.

† For 56Ba, Dauvillier (5, 47) lists the following non-diagram lines: $\alpha_4\lambda$ = 2732.7, $\beta_2'\lambda$ = 2395.4, $\gamma_1'\lambda$ = 2232.4, $\gamma_4'\lambda$ = 2067.5.

‡ Siegbahn (142) gives for $\beta_{13}\lambda_{Sa}$ = 1987.1, λ_{Eu} = 1909.2.

§ Non-diagram lines listed by Siegbahn (142).

‖ Dauvillier (5, 47) gives for $\beta_{14}\lambda_{Ce}$ = 2212.4, λ_{Nd} = 2039.5, λ_{Sm} = 1886.0, λ_{Eu} = 1813.9.

¶ Also called β_2'' by the same author.

TABLE 11.—(*Continued*)

G. Sources (except as otherwise noted).—Absorption limit: *K*-limits (24), *L*-limits, 65Tb (L_{11}) and 67Ho (127), 65Tb (L_{22}-L_{21}) and 70Yb (74), others (41). Emission: *K*-series 67Ho (109), others (32, 33); *cf.* (109). *L*-series, 69Tu (37), β_5 (L_{22}-$O_{32, 33}$), and γ_6 (L_{21}-O_{32}) (5, 48), others (142); *M*-series (83).

Lines		64Gd	65Tb	66Dy	67Ho	68Er	69Tu	70Yb	71Lu
α_1	M_{33}-N_{44}								7820
α''*								8111	7803
α'*								8090	7787
β	M_{32}-N_{43}								7582
β''*					8919			7870	7560
β'*								7852	
γ	M_{22}-$N_{32,33}$								6780
l	L_{22}-M_{11}	2307.1	2229.0	2154.0	2082.1	2015.1		1890.0	1831.8
α_2	L_{22}-M_{32}	2052.62	1982.31	1915.64	1852.06	1791.40	1733.9	1678.9	1626.36
α_1	L_{22}-M_{33}	2041.93	1971.49	1904.60	1840.98	1780.40	1722.8	1667.79	1615.51†
η	L_{21}-M_{11}			1892.2	1822.0	1754.8	1692.3	1631.0	1573.8
β_4	L_{11}-M_{21}	1849.3	1781.4	1716.7	1655.3	1596.4	1541.2	1488.2	1437.2
β_1	L_{21}-M_{32}	1842.46	1772.68	1706.58	1643.52	1583.44	1526.8	1472.5	1420.7
β_{13}‡		1835.5	1765.5	1699.2	1635.5	1575.6			
β_3	L_{11}-M_{22}	1810.9	1742.5	1677.7	*1616.0*	*1557.9*	*1502.3*	*1449.4*	*1398.2*
β_6	L_{22}-N_{11}	1803.1	1737.5	1677.7	1618.8	1563.6	1511.5	1462.7	1414.3
β_{14}‡		1748.1†	1685.1	1625.1	1567	1512			
β_2	L_{22}-$N_{32,33}$	1741.9	1679.0	1619.8	1563.7	1510.6	1460.2	1412.8†	1367.2†
$\beta_2'\beta_2''$‡ ($\beta_{11,12}$)						1501.4			1359
β_9§	L_{11}-M_{32}	1729.3							*1339.8*
β_{10}‡		1728.1	1664						*1339.8*
β_9‡						*1482.3*			*1333.0*
β_8§	L_{11}-M_{33}	1720.0							*1333.0*
β_7§	L_{22}-$N_{43,44}$								1346.6
β_7	L_{22}-O_{11}	1719.6	1655.8	1595.7		1489.2			1345.9
β_9‡						1482.3			*1333.0*
β_5	L_{22}-$O_{32,33}$	1709.3							1339.8
	L_{22}-limit	1706.2†	1644.2	1587.0	1532.2	1479.6	1429.9	1382.64	1337.7
γ_5	L_{21}-N_{11}	1637.6	1574.2	1515.2	1459	1403	1352.3	1303.0	1256
γ_9‡		1593.6†	1531.4		1416				
γ_1	L_{21}-N_{32}	1588.63	1526.6	1469.7	1414.2	1362.3	1312.7	1264.8	1220.3
γ_{10}§		1578.9						1256.8	1211.9
γ_6§	L_{21}-N_{43}	1569.5						1248.3	1201.6
γ_6	L_{21}-O_{32}	1561.5						1240.5	1196.9
	L_{21}-limit	1558.7	1499.4	1441.4	1386.9	1334.9	1284.9	1238.14	1194.5
γ_2	L_{11}-N_{21}	1531.0†	1473.8	1420.3	1367.7	1318.4	1271.2	1225.6	1183.2
γ_3	L_{11}-N_{22}	1525.9	1468.3	1413.9	1361.3	1311.8	1265.3	1219.8	1177.5
γ_9§	L_{11}-N_{33}	1538.3						1201.6	1160.5
γ_4	L_{11}-$O_{21,22}$	1481.8	1423.9	1371.4	1319.7	1273.2	1226.4	1182.0	1141.1
	L_{11}-limit	1474.0	1417.0	1364.8	1314.6	1266.0	1219.6	1176.4	1136.2
α_2	K-L_{21}	292.41	282.94	273.64	264.99	256.72	248.61	240.99	233.58
α_1	K-L_{22}	287.73	278.19	268.87	260.30	251.99	243.87	236.22	228.82
β_3	K-M_{21}	254.71	246.29	237.87		223.00	215.58	209.16	202.52
β_1	K-M_{22}	253.94	245.51	237.10		222.15	214.87	208.34	201.71
β_2	K-$N_{21,22}$	247.62	239.12	231.28		216.71		203.22	196.49
	K-limit	246.2	237.6	230.1	221.8	215.8	208.5	201.6	195.1

* Satellites of diagram lines; not resolved in any photograph (83). $M\alpha$ and $M\beta$ are unresolved multiplets; for details of structure, *see* (166).

† Other non-diagram lines listed by Dauvillier (5, 47) are: For 64Gd, $\beta_{14}\lambda$ = 1748.7, $\beta_{10}\lambda$ = 1703.3, $\gamma_1'\lambda$ = 1594.6, $\gamma_7'\lambda$ = 1538.3; for 70Yb, $\beta_2''\lambda$ = 1405.9; for 71Lu, $\alpha_3\lambda$ = 1612.2, $\beta_2'\lambda$ = 1368.9, $\beta_2''\lambda$ = 1357.9.

‡ Non-diagram lines listed by Siegbahn (142).

§ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's β_7 and β_7' are entered as β_7' and β_7, respectively. His β_2'', β_8, β_9 are, respectively, same as Siegbahn's β_8, β_9, β_{10}.

TABLE 11.—(*Continued*)

H. Sources (except as otherwise indicated).—Absorption limit: *K*-limits, 72Hf and 73Ta [24], 74W (*see* Table 7), others [59]; *L*-limits, 72Hf [41], 73Ta and 74W [127], others [63, 66]; *M*-limits, 74W [197] and 76Os, 77Ir, and 78Pt [136]. Emission: *K*-series, 72Hf [33]; *cf.* [109], others [58]; *L*-series in ( ) [81], 72Hf [37], 73Ta stronger [188], others [36], corrected, 76Os (η, β_2, β_3, β_4, β_5, β_6, β_7, γ_5, γ_6), 77Ir (η, β_7, γ_4, γ_5), and 79Au (β_3, L_{21}-P_{11}, L_{22}-P_{11}) [47]; others [142]; *M*-series, 72Hf [37], 74W [161], others [83].

Lines		72Hf	73Ta	74W*	76Os	77Ir*	78Pt*	79Au*
	M_{33}-N_{22}					8012		*x*
	M_{22}-N_{11}			7349	6882	6663		6264
α_1	M_{33}-N_{44}	7521	7238	6963	6481	6250	6041	5831
α''†				6952	6459	6223	6026	5812
	M_{32}-$O_{21,22}$			6750				
β	M_{32}-N_{43}	7286	7001	6733	6256	6030	5820	5619
β''†				6726	6233	6011	5797	
	M_{33}-limit			6708	6194	5961	5736	
	M_{32}-limit			6475	5975	5754	5541	
	M_{21}-N_{11}			6271	5802			
γ	M_{22}-N_{32}		6301	6123	5672	5484	5303	5131
γ	M_{22}-N_{33}			6083				
γ'				6066	5652			
	M_{22}-O_{11}			5607				
	M_{22}-limit			5416	5027	4851	4674	
	M_{21}-N_{32}			5365	4949	4768	*x*	*x*
	M_{11}-N_{22}			5157	4779	4548	4407	4230
	M_{21}-limit			4800	4412	4270	3738	
	M_{11}-$O_{21,22}$			4433				
	M_{11}-limit			4365	4037			
l	L_{22}-M_{11}	1777.4	1724.2	1675.05			1497.23	1456.54
				(1675.0)				
t‡			1671.7	1621.6		1490.0	1449.0	1410.0
s‡			1608.6	1561		1429.5		1348.1
α_2	L_{22}-M_{32}	1577.04	1529.8	1484.52	1398.2	1359.39	1321.21	1284.89
				(1484.38)		(1359.8)	(1321.55)	(1285.02)
α_1	L_{22}-M_{33}	1566.07	1518.85	1473.48	1388.16	1348.34	1310.08	1273.55
				(1473.36)		(1348.47)	(1310.33)	(1273.77)
α_3‡			1514.3		1383.2	1343.3	1304.9	1268.9
η	L_{21}-M_{11}	1519.7	1465.5	1417.7	1325.8	1283.6	1240.1	1199.5
				(1418.1)				
β_{11}‡	L_{11}-M_{11}		1383.3	1334.4		1204.4	1163.4	
β_4	L_{11}-M_{21}	1389.3	1343.1	1298.74	1215.0	1176.4	1139.8	*1104.4*
				(1298.79)				
β_6	L_{22}-N_{11}	1371.1	1327.4	1287.1	1204.8	1171.7	1139.8	1110.6
				(1287.0)				
β_1	L_{21}-M_{32}	1371.1	1324.23	1279.17	1194.59	1154.95	1117.22	1080.93
				(1279.17)		(1155.40)	(1117.58)	(1081.28)
β_3	L_{11}-M_{22}	1349.7	1304.1	1260.00	1177.2	1137.9	1099.50	1065.2
				(1259.92)				
β_2	L_{22}-$N_{32,33}$	1323.5	1281.90	1241.91	1168.38§	1132.87	1099.50§	*1067.75*§
				(1242.03)		(1132.97)	(1099.74)	(1068.01)
β_2''‡			1275.0	1236.0	1161.6	1127.3	1094.1	1061.0‖
β_2', β_2''¶ (β_8)			1274.7	1235.4**		1126.7	1092.8	1060.9
β_7	L_{22}-O_{11}	1303.5	1260.9	1220.8	1147.9††	1111.6††	1078.5	1046.5
β_7‡	L_{22}-$N_{43,44}$					1108.2	1076.2	1045.3
	L_{22}-limit	1293.0	1251.7	1211.6			1070.9	1038.7
β_5	L_{22}-$O_{32,33}$		1251.5	1212.5	1140	1103.0	1070.1	1038.2
				(1202.5)				
	L_{22}-P_{11}							1036.0
β_9‡	L_{11}-M_{32}		*1251.8*	1210.5		1097.7	1059.3	*1025.4*
β_{10}¶			1251.5	1209.4			1057.0	1025.7
β_8‡	L_{11}-M_{33}		1243.0	1203.4	1123.8	1087.4	1052.4	*1018.2*
β_9¶			1243.8	1202.1			1051.9	1018.8
γ_5	L_{21}-N_{11}	1212.1	1170.9	1129.2	1054.1	1019.7	985.5	954.2
γ_1	L_{21}-N_{32}	1176.5	1135.58	1095.53	1022.47	988.41	955.45	924.37
				(1096.30)		(988.76)	(955.99)	(924.61)
γ_{10}‡			1129.0	1088.7		982.2	950.3	

TABLE 11*H*.—(*Continued*)

	Lines	72Hf	73Ta	74W*	76Os	77Ir*	78Pt*	79Au*
γ_8	L_{21}-O_{11}			1079				
γ_6‡	L_{21}-N_{43}		1117.6	1078.5	1005.3	971.4	937.9	907.5
γ_6	L_{21}-O_{32}		1110.9	*1072.0*	999.1	963.6	*931.7*	901.25
	L_{21}-limit	1151.5	1110.2	1071.3			932.1	*901.1*
γ_2	L_{11}-N_{21}	1141.3	1102.9	1065.84	995.7	963.6	931.7	901.25
				(1065.88)				
	L_{21}-P_{11}							899.0
γ_3	L_{11}-N_{22}	1135.6	1097.1	1059.65	988.8	956.6	925.6	895.68
				(1059.87)				
γ_9‡	L_{11}-N_{33}			1043.9	975.0	942.6	912.0	883.0
γ_4	L_{11}-$O_{21,23}$	1100.1	1063.3	1026.47	957.2	924.5	895.0	866.3
				(1025.8)				
	L_{11}-limit	1097	1057	1020.5			892.1	861.3
α_2	K-L_{21}	226.53	219.73	213.45	201.31	195.50	190.04	184.83
α_1	K-L_{22}	221.73	214.88	208.62	196.45	190.65	185.23	179.96
β_3	K-M_{21}	195.83						
β_1	K-M_{22}	195.15	189.91	184.22	173.61	168.50	163.70	159.02
β_2	K-$N_{21,22}$	190.42	184.52	178.98	168.75	163.76	158.87	154.26
	K-limit	190.1	183.6	178.07			158.1	153.4

* Friman's measurements (81) of the stronger lines are given in ( ) and are more accurate than the older values; he did not measure the fainter lines.

† Satellites of diagram lines: not resolved in any photograph (83). $M\alpha$ and $M\beta$ are unresolved multiplets, for details of structure, *see* (166).

‡ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's β_7 and β_7' are entered as β_7' and β_7, respectively. His β_2'', β_8, β_9 are, respectively, same as Siegbahn's β_8, β_9, β_{10}.

§ Dauvillier (5, 47, 48) lists separately β_2' with λ_{Os} = 1170.2, λ_{Pt} = 1100.9, λ_{Au} = 1069.75.

‖ Dauvillier (5, 47) lists $\beta_2'''\lambda$ = 1062.3 for 79Au.

¶ Non-diagram lines listed by Siegbahn (142).

** Same observer lists this value for $\beta_{11,12}$ also.

†† As measured by Dauvillier and called by him β_7'; his β_7 is the neighboring non-diagram line L_{22} - $N_{43,44}$.

I. Sources (except as otherwise noted).—Absorption limit: *K*-limits (59); *L*-limits, 88Ra (19), others (63, 66); *M*-limits (34, 154). Emission: *K*-series, 92U (135), others (58); *L*-series in ( ) (81), 80Hg (75), 84Po and 88Ra (19), 92U (γ_4 and L_{11}-$P_{21,22}$) (47), others (142); *M*- and *N*-series (83).

	Lines	80Hg*	81Tl†	82Pb‡	83Bi†	84Po	88Ra	90Th†	92U†
	N_{22}-$O_{32,33}$							13 805	12 874
	N_{22}-P_{11}							13 149	12 250
	N_{21}-O_{32}							11 046	10 385
	N_{11}-$O_{21,22}$							10 030	9 619
	N_{11}-$P_{21,22}$				13 208			9 397	8 691
	M_{33}-N_{22}			6 727	6 498			5 245	4 929
	M_{22}-N_{11}		5 879	5 687	5 525			4 569	4 326
α_2	M_{33}-N_{43}				5 117			4 138	3 913
α_1	M_{33}-N_{44}		5 443	5 273	5 107			4 129	3 901
α''§			5 427	5 250	5 078			4 097	3 885
α'§				5 242					
β	M_{32}-N_{43}		5 233	5 065	4 894			3 931	3 709
β''§			5 210	5 042	4 875			3 925	3 696‖
β'§								3 921	3 684
	M_{32}-$O_{21,22}$		5 185	4 994	4 815			3 792	3 570
	M_{33}-P_{22}							3 753	3 514
	M_{33}-limit				4 762			3 721	3 491
γ	M_{22}-$N_{32,33}$		4 806	4 666	*4 513*			3 657	3 472
γ'§			4 798		*4 497*			3 645	3 459‖
	M_{32}-limit				4 569			3 552	3 326
	M_{21}-N_{11}			4 646	x			3 530	3 321
	M_{22}-O_{11}							3 276	3 107
	M_{22}-$O_{32,33}$							3 109	2 927
	M_{11}-N_{21}				3 884			3 127	2 909
	M_{22}-limit				3 894			3 058	2 873
	M_{21}-N_{32}		4 095	3 945	3 816			2 999	2 815
	M_{11}-N_{22}		3 932	3 789	3 672			2 917	2 750
	M_{21}-O_{32}							2 612	2 439
	M_{21}-limit							2 571	2 385
	M_{11}-$O_{21,22}$							2 437	2 299
	M_{11}-$P_{21,22}$								2 248

TABLE 11*I*.—(*Continued*)

	Lines	80Hg*	81Tl†	82Pb‡	83Bi†	84Po	88Ra	90Th†	92U†
	M_{11}-limit							2 388	2 228
l	L_{22}-M_{11}	1 418.41		1 346.62	1 312.95			1 112.41	1 064.77
s¶		1 380.6**							961.7
α_2	L_{22}-M_{32}	1 249.51	1 216.03	1 183.52	1 153.3			965.24	920.14
α_1	L_{22}-M_{33}	1 238.48	1 204.71	1 172.02	1 141.15	1 101	1 010	953.42	908.33
			(1 204.93)	(1 172.58)	(1 141.50)			(954.05)	(908.74)
η	L_{21}-M_{11}	1 161.6	1 125	1 090.2	1 057				802.9
β_6	L_{22}-N_{11}	1 076.8	1 048.0	1 018.8	991.6			826.2	786.6
β_4	L_{11}-M_{21}	1 069.2	1 037.1	1 004.69	975.4			789	745.4
β_1	L_{21}-M_{32}	1 045.49	1 012.66	979.90	*949.30*	920		*762.59*	*718.07*
			(1 012.99)	(980.83)	(*950.02*)			(*763.56*)	(*718.51*)
β_2	L_{22}-$N_{32,33}$	1 036.55	1 007.86	979.90	952.93			791.08	752.68††
			(1 008.22)		(953.24)			(791.92)	(753.07)
β_8‡‡		1 030.46		973.5					
β_3	L_{11}-M_{22}	1 030.46	997.8	966.02	935.7			*752.1*	*708.4*
β_2''¶									745.9
β_7¶	L_{22}-$N_{43,44}$								*734.0*
β_7	L_{22}-O_{11}	1 015.5	988	959.0					736
β_5	L_{22}-$O_{32,33}$	1 006.7	978.3	*949.52*	922.3			762.59	724.13
	L_{22}-limit		977.9	950.0	921.9		802	759.9	721.6
β_9¶	L_{11}-M_{32}	984.2							685.3
β_8¶	L_{11}-M_{33}								679.7
β_9‡‡				922.3	893.8				
γ_5	L_{21}-N_{11}	922.9	894.2	863.9	837.8				
γ_1	L_{21}-N_{32}	893.53	865.29	837.08	810.65			651.03	612.83
			(865.71)	(838.01)	(811.43)			(651.76)	(613.59)
γ_2	L_{11}-N_{21}	872.4	844.7	818.2	792.9				604.4
γ_3	L_{11}-N_{22}	*866.2*	*837.9*	813.70	787.4				597.0
γ_6	L_{21}-O_{32}	872.4	*841.7*	813.70	787.4			630.1	592.6
	L_{21}-limit	870.3	841.8	813.6	787.4		668	628.8	592.0
γ_4	L_{11}-$O_{21,22}$	836.1	810.0	783.6	761				573.8
	L_{11}-$P_{21,22}$								568.9
	L_{11}-limit	833.8	805.8	780.6	756.5			604.6	568.7
α_2	K-L_{21}		174.66	170.04	165.25				130.95
α_1	K-L_{22}		169.80	165.16	160.41				126.40
β_3	K-M_{21}		150.11	146.06	142.05				111.87
β_1	K-M_{22}								
β_2	K-$N_{21,22}$		145.39	141.25					108.42
	K-limit	149.1	144.8	141.0	137.2			113.1	107.5

* For 80Hg there are also β_{10} = 993.6 and the unallocated lines 907.6, 882.9, and 856.4, all from (75). *See also* note "†."

† Friman's measurements (81) of the stronger lines are given in ( ) and are more accurate than the older values; he did not measure the fainter lines.

‡ The λ's of the *L*-series of Hönigschmidt's Ra-G (atomic weight = 206.05) are identical (within 0.5mÅ) with those of ordinary Pb (atomic weight = 207.18) (145); those of the $L\alpha_1$ line of such leads are identical within 0.006mÅ (29); those of the absorption limits of two of Richards' leads (atomic weight = 206.08 and 207.20) are identical within 1mÅ (70). *See also* note "†."

§ Satellites of diagram lines; not resolved in any photograph (83).

‖ In spectrum of 92U, $M\beta''$ and $M\gamma'$ are each accompanied by a satellite: $\beta'''\lambda$ = 3700, $\gamma''\lambda$ = 3466.

¶ Non-diagram lines listed by Dauvillier (5, 47); if a difference notation is given, it is to be regarded as tentative. In this table, Dauvillier's β_7 and β_7' are entered as β_7' and β_7, respectively. His β_2'', β_8, β_9 are, respectively, the same as Siegbahn's β_8, β_9, β_{10}.

** An unallocated line; not *s*.

†† Dauvillier (5, 47, 48) lists separately $\beta_2'\lambda$ = 754.68 for 92U.

‡‡ Non-diagram lines listed by Siegbahn (142).

Notes regarding the data of Table 11

Lit.	Remarks	Lit.	Remarks
(19)	Error not stated.	(47)	Values for strong lines are generally within 0.1mÅ of Siegbahn's, but for such lines as $L\beta_3$ and $L\beta_4$ they depart irregularly by about 0.4mÅ.
(23)	Neither error nor value used for grating-space is given.		
(24)	Used rock salt and Siegbahn's value d_r = 2.814 Å, but values may not be strictly comparable with those obtained with calcite.	(5, 48)	Probable error estimated as some tenths of mÅ. Values are based upon Siegbahn's values for *K*-lines of 26Fe and 29Cu.
(32)	Probable error $K\beta_2$ may amount to 0.24mÅ; of others it is 0.08mÅ.	(59)	Probable error estimated as $<\frac{1}{3}$%; recomputation would add only 0.5 unit in last figure.
(33)	These revised data agree fairly well with those by (109).	(60)	Probable error not stated; used ionization spectrometer and estimated position of middle point of the discontinuity to within 0.1% of glancing angle.
(34)	Error not stated.		
(37)	Error estimated as 2mÅ.		

Notes regarding the data of Table 11.—(*Continued*)

Lit.	Remarks
(63, 66)	Error estimated as 0.3 or 0.4mÅ for most of L_{21}- and L_{22}-limits, and, on the average, as *ca.* 0.9mÅ for L_{11}-limits. Data have been recomputed on basis of d_c = 3.02904 Å (*see* Table 9).
(75)	Measurements for 80Hg were relative to neighboring lines of other elements; λ's used for latter were not very accurate.
(72, 80)	Error not stated; crystal was sugar; data have not been recomputed, those for 12Mg and 13Al are the least accurate.
(83)	Error estimated as 2′ to 4′ in the doubled glancing angle; *i.e.*, 1.5 to 3mÅ for calcite and more for gypsum and sugar; all three crystals were used. In certain cases, his difference notation has been changed to conform with indications of the selection rules (p. 31). Dolejsek (55) questions the correctness of some of the transitions assigned to lines of the *N*-series, but the alternatives he proposes seem to be inconsistent with the observed intensities.
(105)	Measurements carefully made and usually agree with those of (108) within 0.1 or 0.2mÅ.
(108)	Probable error not > few units in last figure; work was done in Siegbahn's laboratory.
(110)	Values based on λ = 1242.1mÅ for $L\beta_2$ of W and on white lines, at 2515.7mÅ and 2451.5mÅ, due to Overn effect (131) in his rock salt crystal; assumes d_r = 2.8125 Å. Data not recomputed as the assumed value of $L\beta_2$ of W is essentially that given in Table 9.
(114)	Error not stated; individual plates differ from the mean by only 0.1 or 0.2mÅ.
(116, 117)	A careful investigation.
(118)	Error not stated. Part of the work was done with Siegbahn's precision spectrometer.
(135)	Probable error = 0.1mÅ. Used de Broglie's rotating crystal method. Kind of crystal is not stated, but probably differences between his values and Cork's (32) may be judged from their values for W as given in Table 9.
(142)	Probable error in *K*-series is not > a few units in last figure.
(151)	Most of their values are given only to nearest 10mÅ. They do not state to which $L\beta$ their measurements apply, presumably it is $L\beta_1$.
(154)	Error not stated.
(167)	Probable error of $K\alpha_1$ and $K\alpha_2$ = 0.04mÅ, of $K\beta_1$ = 0.06mÅ.

ABSORPTION LIMITS

As the wave-length (λ) of the radiation is varied the coefficient of absorption of a given substance changes abruptly as λ passes through certain definite values. These values are known as the absorption limits of the substance, and have been found to coincide with the limiting frequencies of the emission series characteristic of the absorber; for more detailed information, *see* Absorption and scattering of X-rays, p. 8. In this section we are concerned only with the fine structure of these limits and with the effect of chemical combination. For numerical values of the limits, *see* Tables 10 and 11.

Table 12.—Absorption Limits: Fine Structure and Effect of Chemical Combination

The limits for certain elements have a fine structure (38, 72, 80). The structure on the long-λ side may be due to a partial reduction of the compound (113, 114); that on the short-λ side is observed only when the absorbing screen is thin. In addition to the following data, very extensive and detailed investigations may be found in (4, 153).

Roman subscripts indicate the valency of the element in the compound studied. ΔV_c = amount by which the equivalent excitation potential for the compound exceeds that for the uncombined element; $\Delta V_c = \left(\frac{1}{\lambda_c} - \frac{1}{\lambda_e}\right)\frac{hc}{e} = hc\Delta\lambda/e\lambda_c\lambda_e$, where $\lambda_c[\lambda_e]$ = wave-length of absorption limit for compound [for element] and $\Delta\lambda \equiv \lambda_e - \lambda_c$. On basis of I. C. T. accepted constants (Vol. I, p. 17), hc/e = 12 344 volt Å. K_1 = principal *K*-limit, K_2 = secondary absorption edge; in each case λ corresponds to the low frequency edge of the line; δλ = width of line (*cf.* Fig. 14); av. = average. Unit of λ = 1mÅ = 0.001 Å = 10^{-11} cm; of ΔV = 1 volt.

Z	Absorber	λ	ΔV_c	Lit.
	K-limit			
14	Si*.....	6731.0		(114)
	Si_{IV}.....	6707.5	6.4	(114)
15	P(white)*.....	5776.9		(152)
	P(black).....	5771.5	2.0	(152)
	Hypophosphites.....	5757.5	7.2	(152)
	Phosphites.....	5754.1	8.4	(152)
	Phosphates.....	5750.7	9.7	(152)
16	S (*see* below).....			
17	Cl (*see* below).....			
19	K*.....	3431.0		(113)
	KCN.....	3429.3	1.8	(113)
	KCNS.....	3428.7	2.4	(113)
	KI.....	3428.3	2.8	(113)
	KCl.....	3428.0	3.1	(113)
	$K_2S_2O_8$.....	3427.3	3.9	(113)
	K_2SO_4.....	3426.7	4.5	(113)
	$KClO_4$.....	3426.3	4.9	(113)
20	Ca (*see* below).....			
21	Sc.....			
	$Sc_2(SO_4)_3$.....	2751.7		(72, 80)
22	Ti*.....	2491.2		(114)
	TiO_2.....	2482.6	17.0	(114)
23	V*.....	2263.0		(114)
	V_V(av.).....	2257.1	14.2	(114)
24	Cr*.....	2066.3		(114)
	Cr_2S_3.....	2063.9	6.9	(114)
	$Cr(OH)_3$.....	2061.9	12.7	(114)
	$Cr_2(SO_4)_3$.....	2062.2	11.9	(114)
	Cr_{VI}(av.).....	2059.7	19.1	(114)
25	Mn*.....	1892.1		(114)
	Mn_{II}(av.).....	1889.3	9.7	(114)
	MnO_2.....	1887.7	15.2	(114)
	$KMnO_4$.....	1886.3	20.0	(114)
26	Fe*.....	1740.5		(114)
	FeS.....	1738.9	6.5	(114)
	$FeSO_4$.....	1738.3	9.0	(114)
	Fe_{III}(av.).....	1737.2	13.5	(114)

TABLE 12.—(*Continued*)

Z	Absorber	λ (142)		δλ		ΔV_c		ΔV,
		K_1	K_2	K_1	K_2	K_1	K_2	K_2-K_1
17	Cl_2*.....	4393.8	4381.6	7.5				7.8
	HCl.....	4385.3				5.4		
	Chlorides.....	4382.9	4360.0	11.3		7.0	13.8	14.6
	Chlorates.....	4376.9	4357.4	9.6		10.8	15.5	12.5
	Perchlorates.....	4369.8	4347.8	9.7	15.9	15.3	21.6	14.1
	(*See* Fig. 14)							
16†	S mon.‡.....	5009.0	4994.6	8.5	8			
	S rhom.‡.....	5008.6	4993.8	7.7	7.7			
	S* cryst.‡.....	5008.8	4994.1	8.1	7.9			
	Sulfides§.....	5009.3						
	Sulfites.....	4996.0	4988.1	4.3	4.2	6.3		
	SO_2.....	5004.5	4996.4	4.0		2.1		
	Sulfates‖.....	4987.9		5.2		10.3		
	S_{II}¶.....	5006.8						
	S_{IV}¶.....	5001.9		5.5		3.4		
	S_{VI}¶.....	4993.9		5.7		7.3		

Z	Absorber	λ (119)				ΔV		
		K_1	K_2	K_3	K_4	K_2-K_1	K_3-K_1	K_4-K_1
20Ca	Ca*(av.).....	3064.3, $CaCO_3$ (av.); 3060.5, ΔV_c = 5.0 (78)						
	$CaCO_3$.....	3060.8	3050.2	3037.9	3023.8	13.8	29.5	49.1
	$CaSO_4.2H_2O$..	3059.1	3047.5	3035.8		15.8	31.6	
	CaF_2.....	3059.9	3047.8	3034.6	3025.3	16.0	33.7	46.2

Z	Absorber	L-limits				
		L_{22}	$(\Delta V_c)_{22}$	$\Delta\lambda_I$**	$\Delta\lambda_d$**	Lit.
50	Sn*.....	3146.9				(25)
	SnO_2.....	3140.6	8	6.9	5.6	(25)
51	Sb*.....	2991.5				(25)
	Sb_2O_3.....	2985.1	9	6.0		(25)
	$KSbO_3$.....	2984.1	10	6.7	7.1	(25)
	Sb*.....	2993.0				(93)
	Sb_2O_3.....	2987.4	7.7			(93)
	Sb_2S_3.....	2987.9	7.0			(93)
	SbI_3.....	2988.7	5.9			(93)
	SbOCl.....	2989.4	5.0			(93)
	$KSbOC_2O_4$††.....	2987.9	7.0			(93)
	$KSbOC_4H_4O_6$‡‡.....	2988.5	6.2			(93)
	$Sb_2O_5.nH_2O$.....	2986.7	8.7			(93)
	Sb_2S_5.....	2991.0	2.8			(93)
	$Cu(SbO_3)_2.nH_2O$....	2987.4	7.7			(93)
	$K_2H_2Sb_2O_7$.....	2986.2	9.4			(93)
52	Te*.....	2847.1				(38)
	H_2TeO_3.....	2842.2	7	4.7		(38)
	H_2TeO_4.....	2840.6	10	6.0	5.6	(38)
53	I*.....	2712				(38)
	KI.....	2712.2	0.3			(38)
	HIO_3.....	2707.1	9	4.4	6.1	(38)
	HIO_4.....	2705.8	11	5.5		(38)

* Absorber from which ΔV_c is measured.

† In general, S_{II} has a pure edge type of limit, while S_{IV} and S_{VI} exhibit absorption lines; the observed subordinate limit of S_{IV} may really be principal limit of S_{VI}, as result of oxidation of the S_{IV} (111, 112).

‡ Mon. = monoclinic; rhom. = rhombic; cryst. = crystallized. Data are averages.

§ Position of both K_1 and K_2, especially K_2, depends upon the nature of the metal ion.

‖ For K_1, λ is independent of nature of metal ion; for K_2 it increases as Z of metal ion increases.

¶ Organic compounds.

** $\lambda(L_{22}) + \Delta\lambda_I = \lambda$ of a light line which probably (25) is the L_{22}-limit of the element formed by a reduction of the compound. $\lambda(L_{22}) - \Delta\lambda_d = \lambda$ of maximum of a broad, diffuse, dark line which appears only when absorbing screen is thin.

†† Potassium antimonyl oxalate.

‡‡ Potassium antimonyl tartrate.

TABLE 12.—(*Continued*)

Z	Absorber	L_{11}	$(\Delta V_c)_{11}$	L_{21}	$(\Delta V_c)_{21}$	L_{22}	$(\Delta V_c)_{22}$	Lit.
53	I*.....	2402		2548		2711		(159)
	NaI.....	2397	11	2542	12	2708	5	(159)
	$NaIO_3$...	2398	9	2544	9	2709	4	(159)
	$NaIO_4$...	2397	11	2541	14	2703	13	(159)

M-limits§§

Z	M_{22}		M_{32}		M_{33}			
	g	*e*	*g*	*e*	*g*	*e*	*g'*	*e'*
90Th	3058.5	3046.3	3552.3	3538.9	3721.3	3704.5		
92U	2873.4	2865.2	3325.5	3312.4	3490.7	3473.7	3458.7	3449.2

§§ Passing from longer to shorter λ's, the intensity of the transmitted radiation varies as follows: At *g* there is an abrupt decrease in intensity, that is the limit itself; at *e* there is an increase in intensity; at *g'* there is a second decrease, followed by another increase at *e'*.

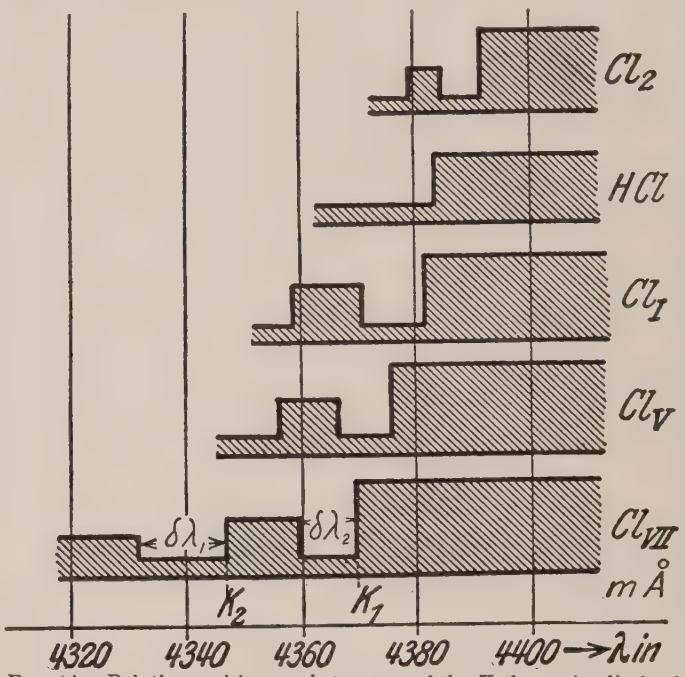

FIG. 14.—Relative positions and structure of the *K* absorption limit of Cl in certain compounds: Diagrammatic. (*After Siegbahn* (142).)

K_1 is the principal limit, K_2 is a secondary edge. The subscripts I, V, VII indicate that the Cl was contained in chlorides, chlorates, and perchlorates, respectively.

CONTINUOUS SPECTRA

All data discussed in this section were obtained with unvarying voltages; the power transmitted by the radiation is proportional to the cathode-ray current (14), and is plotted as ordinates in the figures. (With gas-filled tubes an appreciable fraction of the tube-current may be due to positive ions.) With a fluctuating voltage, the spectral distribution of the energy is much like that with an unvarying *V* equal to the peak voltage, but there is more energy in the longer waves (43); the intensity is practically that due to such current as flows during the part of the cycle when *V* is near its peak value.

Practical workers are interested in the spectral distribution of the energy in the radiation that emerges from the tube. This is roughly indicated in Figs. 15 and 16.

For exact information about atoms and the mechanism of radiation, observed data must be so corrected as to give an actual measure of the X-ray energy *emitted by the atoms of the target;* and, for the purposes of this section, the last is further corrected so as to eliminate the energy contributed by the characteristic line

spectrum of the target. The distribution of energy in such a corrected continuous spectrum is shown in Figs. 17 and 18.

The spectral, or monochromatic, intensity ($J_{\psi\nu}$, $J_{\psi\lambda}$) of the radiation in the direction ψ (*v.* Fig. 19) is defined by the equations $J_\psi = \int_0^{\nu_0} J_{\psi\nu}d\nu = \int_{\lambda_0}^{\infty} J_{\psi\lambda}d\lambda$, where ν_0 and λ_0 correspond to the high-frequency limit of the spectrum, ν_0 being defined by the equation $Ve = h\nu_0$ in which V is the voltage on the tube; $cJ_{\psi\nu} = \lambda^2 J_{\psi\lambda}$. The excitation voltage (V_0) for radiation of frequency ν is $V_0 = h\nu/e$. For notation and general remarks concerning the origin of X-rays and the high-frequency limit of the continuous spectrum, *see* p. 24 and 27.

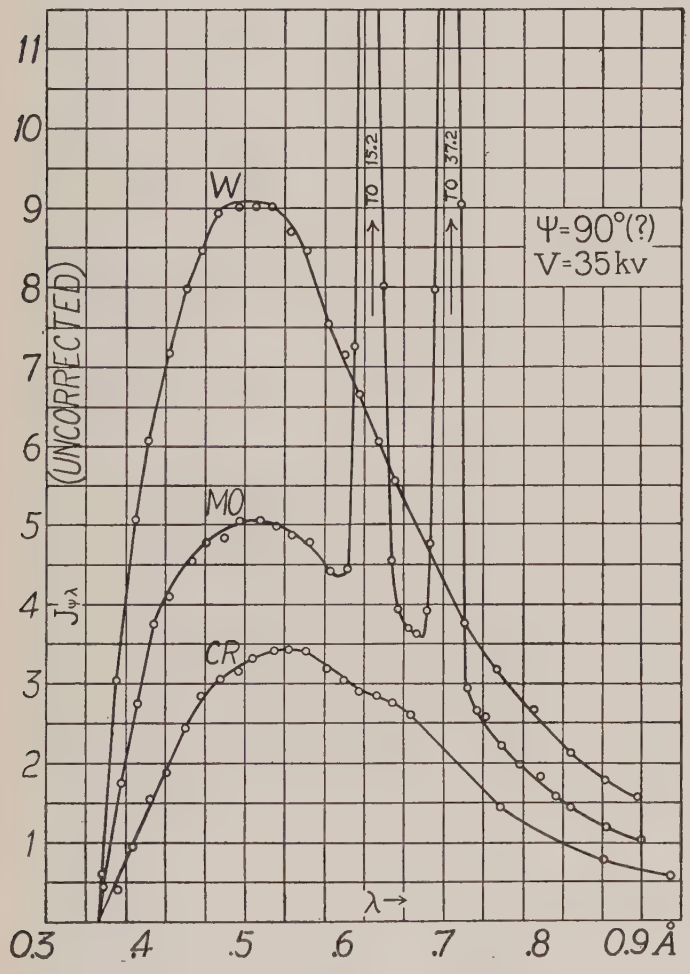

FIG. 15.—Variation of observed (uncorrected) spectrum with material of target [168].

Tube potential and current were unvarying and the same for all.

Under all conditions yet investigated, for radiation from the focal spot, $J_{\psi\nu}d\psi d\nu = CZ[(\nu_0 - \nu) + x]\sin\psi d\psi d\nu$, C is a constant, and x, which is comparatively unimportant, is in general a function of Z, ψ, ν, and ν_0. The $(\nu_0 - \nu)$ term is well established, but investigators disagree regarding the x-term. At low voltages (7 to 12 kv) and $\psi = 90°$, $x = bZ(1 - e^{-(\nu_0-\nu)/\nu_1})$ for a wide range of Z [172, 176] if $b = 0.0025 \times 10^{18}$ sec^{-1} and $\nu_1 = 0.07 \times 10^{18}$ sec^{-1} (*cf.* Figs. 20 and 21). At higher voltages (10 to 80 kv), the isochromat method (Figs. 22 and 23) has usually been used, Z has been varied from 29 to 78, and ψ has been near 90° [177, 186]; but in the most recent work [126], ψ has been varied. In that [126], V was varied from 15 to 80 kv, and it was found that, for $Z = 29$, $x = b'Z\nu_0(1 - e^{-16(\nu_0-\nu)/\nu})$, where for $\psi = 90°$, $b' = 0.0027 \pm 0.0005$; for $\psi = 36°$, $b' = 0.0033 \pm 0.0004$; and for $\psi = 144°$, b'

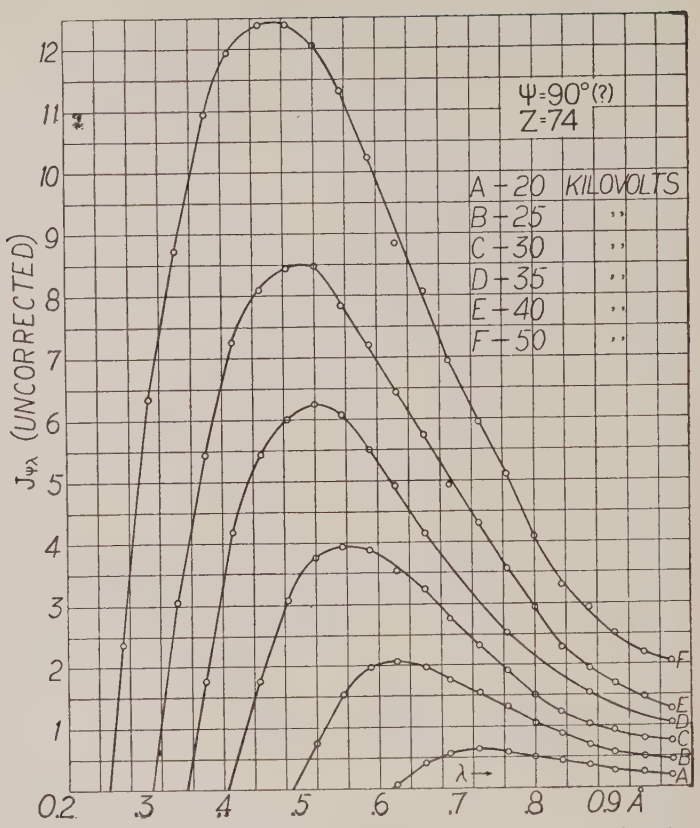

FIG. 16.—Variation of observed (uncorrected) spectrum with tube potential and current constant [168].

In each case the tube potential was unvarying. The tube current was the same in all cases. A standard Coolidge tube with tungsten (W) target was used.

is, in general, negative, progressing from *ca.* 0 for $V_0 = 15$ kv to *ca.* -0.0015 for $V_0 = 50$ kv. The original interpretation of these data was in error; a revision is soon to be published. The total X-ray energy emitted by the focal spot is

$$\int_0^{180°} J_\psi d\psi = \int_0^{180°} \sin\psi d\psi \int_0^{\nu_0} CZ[(\nu_0 - \nu) + x]d\nu = KZV^2 + CZ\int_0^{180°} \sin\psi d\psi \int_0^{\nu_0} x d\nu = ca.\ KZV^2$$

as x is small, positive for some values of ψ and negative for others; K depends upon C, but is independent of Z and of V.

The radiation from the focal spot, to which the formula applies, does not represent all the X-ray energy generated, as a very appreciable fraction of the cathode ray is so deflected from the focal spot as to strike other portions of the target with sufficient velocity to produce X-rays. Probably this effect is much influenced by the smoothness of the target face, and by its inclination to the cathode stream; this may account for the disagreement regarding the x-term. The amount of this stray energy is of the order of 20% of the whole [30, 31], and its spectral distribution is of the same mathematical form as that of the energy from the focal spot, x having a relatively large negative value [126]. For given conditions, the variation of x with ψ is only slightly affected by the presence of this stray radiation [126].

Using the best value of C [102] in calculating the total energy in the continuous spectrum, the efficiency (X-ray energy per volt-ampere of cathode ray current) is found to be $E = (9.5 \pm 3) \times 10^{-10}ZV$, where V is expressed in volts. It is claimed [102] that, in the method of measurement of cathode ray current through the gas-filled tubes used for the above evaluation of C, the stray radiation is automatically corrected for. The best experimental

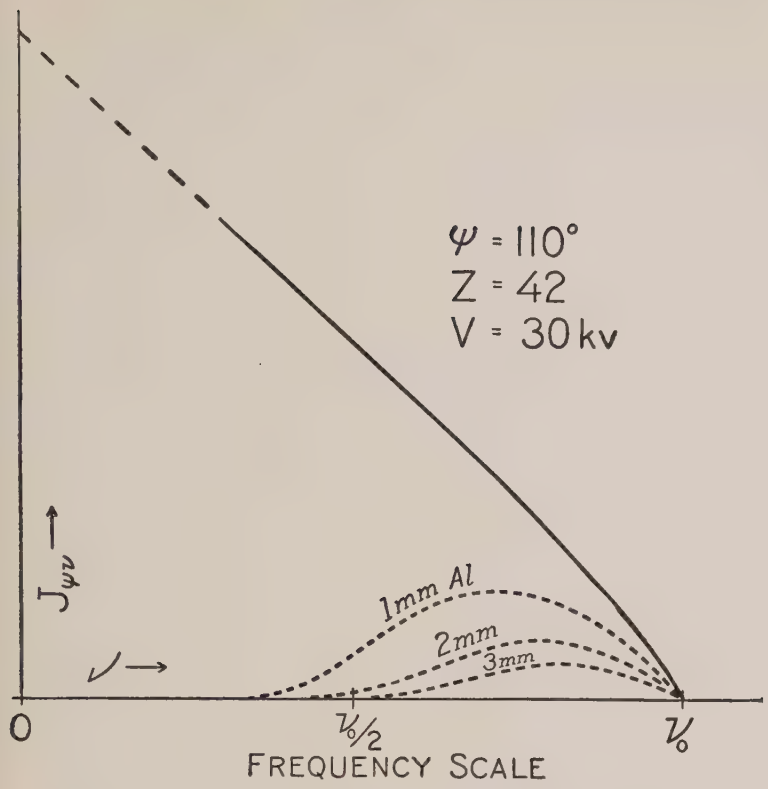

FIG. 17.—Fully corrected frequency spectrum (181).

Full line represents the spectrum as emitted by the atoms of the target; the lower broken lines represent the same after filtration by Al, or, qualitatively, by any filter without absorption limits in the region considered.

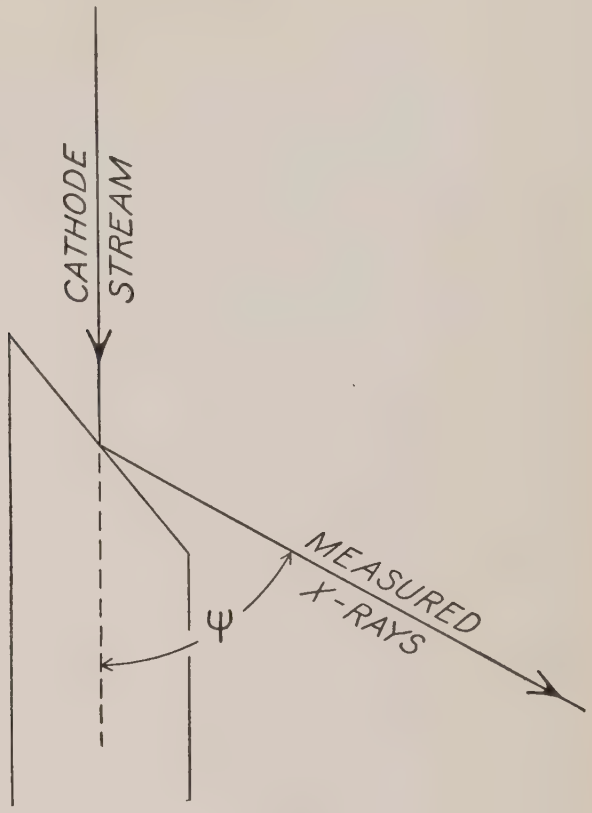

FIG. 19.

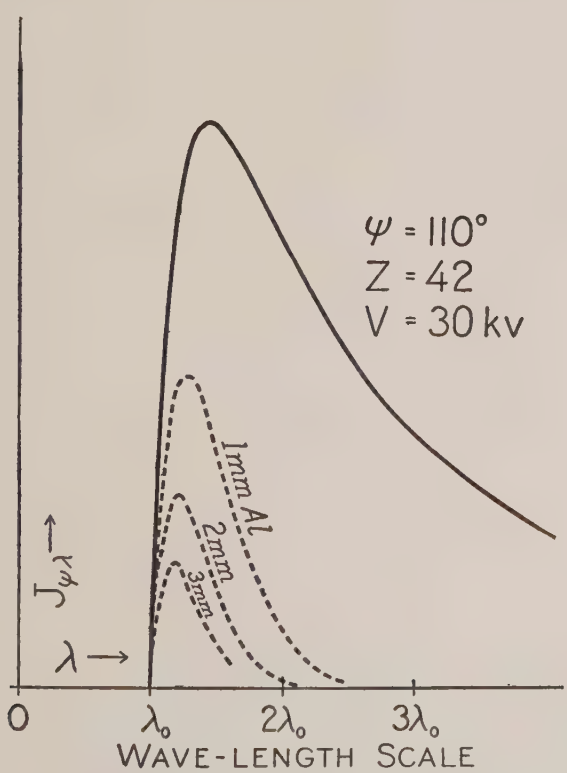

FIG. 18.—Fully corrected wave-length spectrum (181).

This differs from Fig. 17 (*q.v.*) only in the quantity chosen as abscissa (*cf.* p. 46).

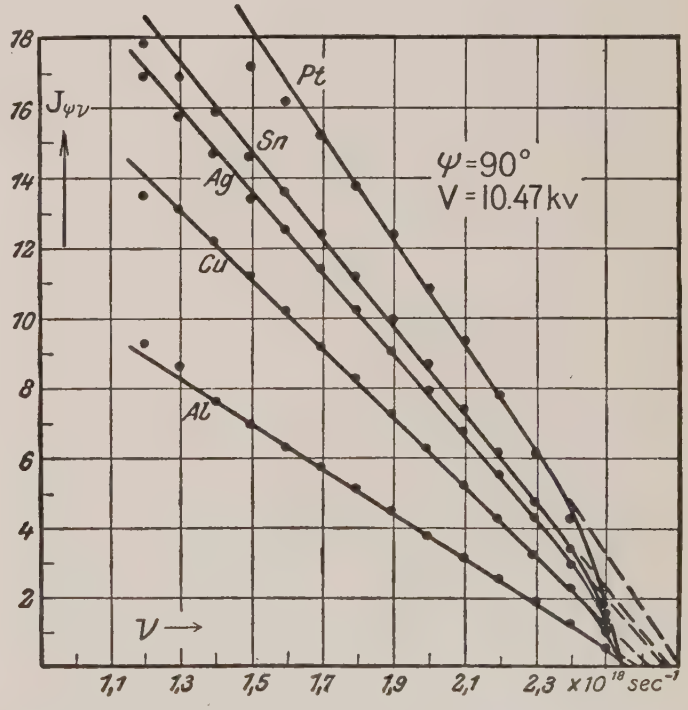

FIG. 20.—Corrected frequency spectrum: Variation with material of target, potential constant (172). (*After Siegbahn* (142).)

Tube potential and tube current were unvarying and the same for all targets.

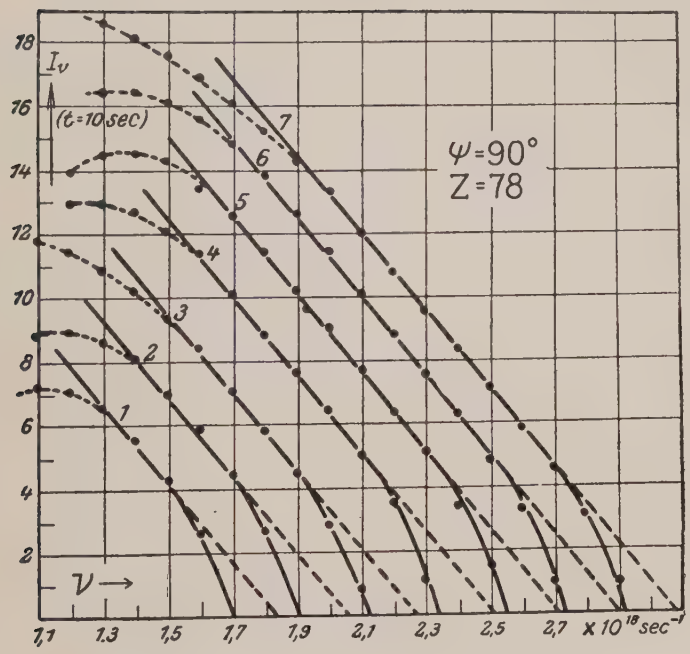

FIG. 21.—Corrected frequency spectrum: Variation with tube potential (172). (*After Siegbahn* (142)).
Tube potential unvarying; tube current is the same in all cases.

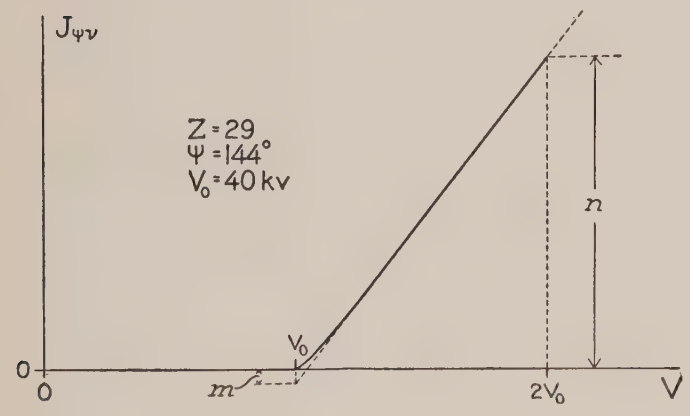

FIG. 22.—An isochromat for Cu ($Z = 29$), $\psi = 36°$ (126).
The ratio m/n is a measure of the x-term in $J_{\psi\nu} = CZ[(\nu_0 - \nu) + x]$. The data may be transferred to an energy frequency graph by means of the total energy law (126, 177, 186).)

method for measuring X-ray energy seems to be that recently used by Rump in a measurement of unresolved energy (138), but his corrections for absorption may be questioned; when his data are corrected on the basis of other work (126, 185), and stray and characteristic radiation allowed for, they lead to a value for the numerical coefficient *ca.* 10×10^{-10}; this is probably the best value available at present. It should be noted that both the above calculations involve the assumption that the formula applies to even the lowest frequencies, of which the energy cannot be measured experimentally owing to absorption in the target and in the walls of the tube.

The most fundamental expression of the laws of X-ray emission will refer to infinitely thin targets, in which the cathode rays have a uniform speed and direction. Such uniformity does not exist in thick targets (185). In them, the cathode rays not only lose speed gradually, until they are completely stopped, but they are also

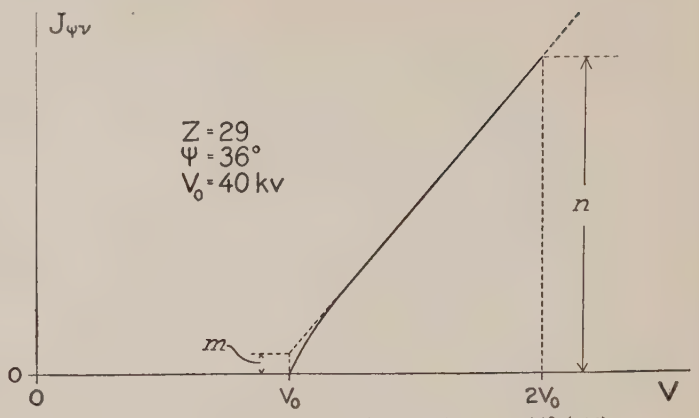

FIG. 23.—An isochromat for Cu ($Z = 29$), $\psi = 144°$ (126). Differs from Fig. 22 (*q.v.*) only in value of ψ.

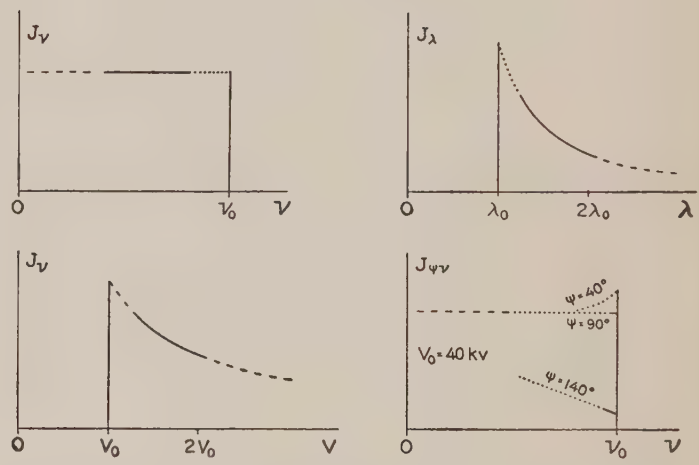

FIG. 24.—Illustrating the continuous spectrum emitted by infinitely thin targets.
Full lines (——) represent data derived from observations with thick targets; dotted lines (. . . .), those from actual thin targets; and broken lines (– – –) are extrapolations.

deflected by the atoms of the target so that, especially for targets of high atomic numbers, they approach random directions by the time they have lost a small fraction of their original energy; *cf.* (185). Hence an expression of the thin target intensity as a function of ψ can be inferred from data for thick targets (126, 176, 186) only if $(\nu_0 - \nu)$ is much less than ν_0; and an average value of the intensity (summed over all values of ψ) can be so inferred only if ν is much less than ν_1. In this way the full line portions of Fig. 24 were obtained from Nicholas' (126) data, the original interpretation of which was in error. Only unpublished preliminary data for actual thin targets are available, but they confirm the conclusions from thick target data, and, within a rather large experimental error, supplement them as indicated by the dotted lines of the figure.

Of numerous theories that have been proposed (15, 18, 52, 100, 121, 191), only one (100) represents satisfactorily the thin target data. This is based on a "correspondence principle" treatment of radiation from electrons in hyperbolic orbits. Its details have been only partially developed, but it leads to an average intensity (over all values of ψ) that agrees with Fig. 24. As applied to thick targets, it leads to the formula here given for the focal spot, but with $x = 0$; and it predicts an efficiency of $9.2 \times 10^{-10} ZV$. Predictions based on wave mechanics are not yet in such form as can be tested by experiment.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Allison, *2*, **30**: 245; 27. (2) Allison and Armstrong, *2*, **26**: 701; 25. (3) Allison and Armstrong, *2*, **26**: 714; 25. (4) Aoyama, Kimura and Nishina, *96*, **44**: 810; 27. **46**: 150; 27. (5) Auger and Dauvillier, *34*, **176**: 1297; 23. (6) Bäcklin, *96*, **27**: 30; 24. (7) Bäcklin, *96*, **33**: 547; 25. (8) Bäcklin, *96*, **38**: 215; 26. (9) Bäcklin, *243*, **47**: 373; 27.

(10) Bäcklin, Siegbahn and Thoraeus, *3*, **49**: 513; 25. (11) Barkla, *3*, **49**: 1033; 25. (11.1) Beatty, *5*, **87**: 511; 12. (12) Beatty, *5*, **89**: 314; 14. (13) Beatty, *5*, **89**: 554; 14. (14) Behnken, *96*, **3**: 48; 20. (15) Behnken, *96*, **4**: 241; 21. (16) Blake and Duane, *2*, **10**: 624; 17. (17) Bohr and Coster, *96*, **12**: 342; 23. (18) Brilloin, *34*, **170**: 274; 20. (19) de Broglie, *B101*.

(20) de Broglie and Dauvillier, *34*, **175**: 685; 22. (21) de Broglie and Dauvillier, *34*, **175**: 755; 22. (22) de Broglie and Dauvillier, *51*, **5**: 1; 24. (23) de Broglie and Lepape, *34*, **176**: 1611; 23. (24) Cabrera, *34*, **176**: 740; 23. (25) Chamberlain, *53*, **114**: 500; 24. (26) Chamberlain and Lindsay, *2*, **25**: 106; 25 (27) Chamberlain and Lindsay, *2*, **30**: 369; 27. (28) Compton, Beets and DeFoe, *2*, **25**: 625; 25. (29) Cooksey and Cooksey, *2*, **16**: 327; 20.

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(50) Dauvillier, *34*, **178**: 1522; 24. (51) Dauvillier, *51*, **8**: 1; 27. (52) Davis, *2*, **9**: 64; 17. (53) Davis, *337*, **1**: 409; 20. (53.1) Davis and Purks, *197*, **13**: 419; 27. (53.2) Davis and Purks, *197*, **14**: 172; 28. (54) Dessauer and Bach, *26*, **21**: 168; 19. (55) Dolejsek, *34*, **178**: 384; 24. (56) Dolejsek, *in B78*. (57) Dolejsek and Siegbahn, *in B78*. (58) Druyvesteyn, *96*, **43**: 707; 27. (59) Duane, Fricke and Stenström, *197*, **6**: 607; 20.

(60) Duane and Hu, *2*, **14**: 516; 19. (61) Duane and Hunt, *2*, **6**: 166; 15. (62) Duane, Palmer and Yeh, *2*, **18**: 98; 21. *197*, **7**: 237; 21. (63) Duane and Patterson, *197*, **6**: 509; 20. (64) Duane and Patterson, *197*, **6**: 518; 20. (65) Duane and Patterson, *2*, **16**: 526; 20. (66) Duane and Patterson, *197*, **8**: 85; 22. (67) Duane and Patterson, *2*, **19**: 542; 22. (68) Duane and Shimizu, *2*, **14**: 67; 19. (69) Duane and Shimizu, *2*, **14**: 525; 19.

(70) Duane and Shimizu, *197*, **5**: 198; 19. (71) Duane and Stenström, *197*, **6**: 477; 20. (72) Dufet, *Recueil de données numériques*. Paris, Gauthier-Villars, 1898–1900. (73) van Dyke and Lindsay, *2*, **30**: 562; 27. (74) Eddy, *58*, **116**: 380; 25. (75) Eddy and Turner, *5*, **111**: 117; 26. (76) Ehrenberg and Mark, *96*, **42**: 807; 27. (77) Ehrenberg and Susich, *96*, **42**: 823; 27. (78) Enger, *96*, **46**: 826; 28. (79) Eriksson, *96*, **48**: 360; 28.

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(100) Kramers, *3*, **46**: 836; 23. (101) Kulenkampff, *8*, **69**: 548; 22. (102) Kulenkampff, *in B95:* **XXIII**. (103) Landé, *63*, **22**: 417; 21. (104) Landé, *96*, **16**: 391; 23. (105) Lang, *8*, **75**: 489; 24. (106) Larsson, *3*, **3**: 1136; 27. (107) Ledoux-Lebard and Dauvillier, *34*, **163**: 754; 16. **164**: 687; 17. (108) Leide, *34*, **180**: 1203; 25. (109) Leide, *Diss.*, Lund, 1925. *96*, **39**: 686; 26.

(110) Lepape and Dauvillier. *34*, **177**: 34; 23. (111) Lindh, *Diss.*, Lund, 1923. *34*, **175**: 150; 22. (112) Lindh, *in B78*. (113) Lindh, *20*, **18**: No. 14; 24. (114) Lindh, *96*, **31**: 210; 25. (115) Lindh and Lundquist, *20*, **18**: No. 17; 24. (116) Lindh and Lundquist, *20*, **18**: No. 34; 24. (117) Lindh and Lundquist, *20*, **18**: No. 35; 24. (118) Lindsay, *34*, **175**: 150; 22. (119) Lindsay and van Dyke, *2*, **28**: 613; 26.

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(130) Ortner, *58*, **117**: 823; 26. (131) Overn, *2*, **18**: 350; 21. (132) Ray, *3*, **48**: 707; 24. (133) Ray, *3*, **49**: 168; 25. (134) Ray, *3*, **50**: 505; 25. (135) Rechou, *34*, **180**: 1107; 25. (136) Rogers, *2*, **29**: 205; 27. (137) Ross, *2*, **22**: 221; 23. (138) Rump, *96*, **43**: 254; 27. (139) Russell and Saunders, *21*, **61**: 38; 25.

(140) Siegbahn, *3*, **37**: 601; 19. (141) Siegbahn, *3*, **38**: 639; 19. (142) Siegbahn, *B78*. (143) Siegbahn and Larsson, *20*, **18**: No. 18; 24. (144) Siegbahn and Ray, *20*, **18**: No. 19; 24. (145) Siegbahn and Stenström, *63*, **18**: 547; 17. (146) Siegbahn and Thoraeus, *20*, **18**: No. 24; 24. (147) Siegbahn and Zacek, *8*, **71**: 187; 23. (148) Slator, *2*, **28**: 291; 26. (149) Sommerfeld, *B94*.

(150) Sommerfeld, *8*, **76**: 284; 25. (151) Sommerfeld, *63*, **26**: 70; 25. (152) Stelling, *93*, **131**: 48; 23. (153) Stelling, *Diss.*, Lund, 1927. *7*, **117**: 161, 175, 194; 25. *25*, **60**: 650; 27. (154) Stenström, *Diss.*, Lund, 1919. (155) Stephenson and Cork, *2*, **27**: 138; 26. (156) Stoner, *3*, **48**: 719; 24. (157) Stoner, *3*, **2**: 97; 26. (158) Stumpen, *96*, **36**: 1; 26. (159) Tandberg, *20*, **18**: No. 14; 24.

(160) Thibaud, *51*, **8**: 447; 27. (160.1) Thomas, *201*, **23**: 829; 27. (161) Thoraeus, *96*, **26**: 396; 24. (162) Thoraeus, *3*, **1**: 312; 26. (163) Thoraeus, *3*, **2**: 1007; 26. (164) Thoraeus and Siegbahn, *20*, **19**: No. 12; 25. (165) van der Tuuk, *96*, **41**: 326; 27. (166) van der Tuuk, *96*, **44**: 737; 27. (167) Uhler and Cooksey, *2*, **10**: 645; 17. (168) Ulrey, *2*, **11**: 401; 18. (169) Unnewehr, *2*, **23**: 529; 23.

(170) Wagner, *8*, **57**: 401; 18. *63*, **21**: 621; 20. (171) Wagner, *200*, **16**: 212; 19. (172) Wagner and Kulenkampff, *63*, **23**: 503; 22. (173) Walter, *96*, **30**: 357; 24. (174) Webster, *197*, **2**: 90; 16. (175) Webster, *2*, **7**: 599; 16. (176) Webster, *2*, **9**: 220; 17. (177) Webster, *197*, **5**: 163; 19. (178) Webster, *197*, **6**: 26; 20. (179) Webster, *337*, **1**: 427; 20.

(180) Webster, *2*, **18**: 155, 321; 21. (181) Webster, *Radiology*, **2**: 214; 24. (182) Webster, *197*, **13**: 445; 27. (182.5) Webster, *197*, **14**: 339; 28. (183) Webster and Clark, *2*, **9**: 571; 17. (184) Webster and Clark, *197*, **3**: 181; 17. (185) Webster and Hennings, *2*, **21**: 301; 23. (186) Webster and Hennings, *2*, **21**: 312; 23. (187) Weeks, *2*, **10**: 564; 17. (188) Wennerlöf, *96*, **41**: 524; 27. (189) Wentzel, *8*, **66**: 437; 22.

(190) Wentzel, *96*, **16**: 46; 23. (191) Wentzel, *96*, **27**: 257; 24. (192) Wentzel, *8*, **73**: 647; 24. (193) Wetterblad, *96*, **42**: 603; 27. (194) Wetterblad, *96*, **42**: 611; 27. (195) Whiddington, *5*, **86**: 360, 370; 12. (196) Wooten, *2*, **13**: 71; 19. (197) Zumstein, *2*, **25**: 747; 25.

REFLECTION AND REFRACTION OF X-RAYS

P. A. Ross

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Symbols

For those not defined here or where used, *see* Vol. I, p. 16

d	Grating space of the crystal lattice.
$I_{\lambda i}$	Ionization produced by monochromatic incident beam.
$I_{\lambda r}$	Ionization produced by monochromatic reflected beam.
k_0	Molecular gas constant.
m_e	Mass of the atom.
N	Spectral order.
n	Number of electrons per unit volume.
l_1, l_2, l_3	Direction cosines of reflecting plane with reference to the axes of the crystal.
s	Length of one edge of the elementary cube of the crystal.
θ	Glancing angle corresponding to λ.
θ_0	Glancing angle if μ were unity. True glancing angle.

λ Wave-length.
μ Index of refraction.
ν Frequency.
ϕ Debye's function (13).
ω Angular velocity of the reflecting crystal.

Refraction.—Darwin's formula (7) is $\theta - \theta_0 = (1 - \mu)/(\sin\theta \cos\theta)$, hence $\lambda = \{1 - (1 - \mu)/\sin^2\theta\}(2d \sin\theta)/N$. From the optical theory of reflection (16), $1 - \mu = \frac{e^2}{2\pi m}\left(\frac{n_1}{\nu^2 - \nu_1^2} + \frac{n_2}{\nu^2 - \nu_2^2} + \ldots\right)$ where n_1, n_2, . . . are the numbers of electrons, per unit of volume, having natural frequencies ν_1, ν_2, . . . Usually ν_1, ν_2, . . . are all small as compared with ν, then $1 - \mu = ne^2/2\pi m\nu^2$.

TABLE 1.—INDEX (μ) OF REFRACTION OF X-RAYS

$\mu = 1 - \delta \times 10^{-6}$; δ_0 = observed; δ_c = computed; ρ = density of refractor; unit of $\lambda = 1$ Å $= 10^{-8}$ cm; of $\rho = 1$ g cm^{-3}

Refractor		ρ	λ	δ_0	δ_c	Lit.
Ag	Silver	10.5	1.279	21.5	19.8	(6)
$CaCO_3$	Calcite	2.71	0.70783	2.03 ±0.1	1.91	(14)
			0.70783	1.7 ±0.5		
FeS_2	Pyrite	5.01	0.63102	2.87 ±0.2	2.66	(17)
			0.6311	2.82	2.62	(8)
			0.7078	3.33	3.29	(8)
			0.70783	3.35 ±0.2	2.34	(17)
			1.389	13.2	13.5	(8)
			1.3892	13.2 ±0.4	13.6	(17)
			1.537	17.6	17.6	(8)
			1.5372	17.6 ±0.5	17.7	(17)
	Glass	2.52	0.52	0.9	0.7	(6)
			1.279	4.2	5.2	(6)
		2.551	0.630	1.22	1.26	(15)
			0.708	1.64	1.60	(15)
			1.389	6.648	6.15	(15)
			1.538	8.125	7.55	(15)
			1.750	10.0	9.75	(15)
			1.933	12.38	11.85	(15)
	Lacquer		1.279	5.1		(6)

Reflection.—The reflectivity depends upon the polish (Table 4) and upon the temperature (Table 3) of the reflecting surface, as well as upon the crystal plane employed.

TABLE 2.—REFLECTIVITY OF ROCK SALT (NaCl) AND CALCITE ($CaCO_3$): X-RAYS

$r(10)^{-5} \equiv E\omega/I$ = integrated reflection; I = intensity of direct beam, E = ionization current, ω = angular velocity of rotation of crystal; $E\omega$ is independent of ω. N = spectral order, Pl = reflecting plane. Crystal surfaces are polished.

NaCl					$CaCO_3$				
Pl	N	λ	r	Lit.	Pl	N	λ	r	Lit.
100	1	0.613	54	(3)	100	1	0.712	8.72	(5)
100	1	0.614	55	(2)	100	1	1.39	7.70	(18)
100	1	0.710	40.3	(5)	100	1	1.54	8.10	(18)
100	1	1.54	27.5	(18)	100	1	1.75	8.07	(18)
100	1	1.93	20	(18)	100	1	1.93	7.88	(18)
100	2	1.54	4.0	(18)	100	2	1.54	0.66	(18)
100	2	1.93	2.9	(18)	100	2	1.93	0.62	(18)

NaCl (2); $N = 1$; $\lambda = 0.614$

Pl	r	Pl	r	Pl	r
100	55	220	3.34	555	0.075
200	10.9	330	0.390	311	0.650
300	2.78	111	4.95	622	1.47
400	0.435	222	18.1	331	0.445
500	0.064	333	0.318	511	0.335
110	0.278	444	1.54	711	0.168

TABLE 2.—(*Continued*)

NaCl (2); relative reflectivity; $\lambda = 0.586$

Pl \ N	1	2	3	4
100	100	18.7	6.25	
110	41	7.05		
111	16.5	24.4	3.1	4.2

TABLE 3.—REFLECTIVITY FOR X-RAYS: VARIATION WITH TEMPERATURE

See also Figs. 1 and 2

Debye (13) finds that the effect of temperature may be represented by the factor F, where

$$F = e^{-\frac{3}{4}\cdot\frac{h^2}{mk_0T_0s^2}N_2(l_1^2 + l_2^2 + l_3^2)\frac{T}{T_0}\phi\left(\frac{T_0}{T}\right)}$$

T = absolute temperature and T_0 is a temperature which is characteristic of the crystal. In certain cases, $r(t_2)/r(t_1) = 1 - a(t_2 - t_1)(10)^{-6}$, where $r(t_2)/r(t_1)$ = ratio of reflectivity at temperature t_2 to that at t_1. Obs. = observed value of $r(t_2)/r(t_1)$, Calc. = value calculated by means of factor F, Pl = reflecting plane, N = spectral order. Unit of $\lambda = 1$ Å $= 10^{-8}$ cm; t = centigrade temperature, °C.

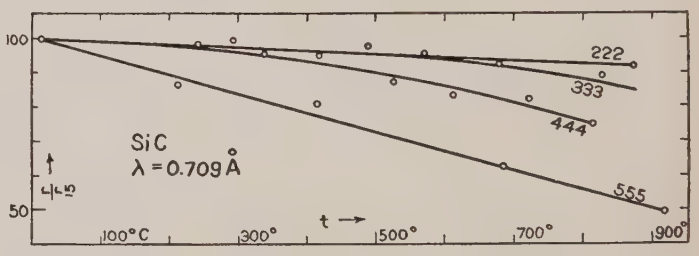

FIG. 1.—Variation of relative reflectivity with temperature: Carborundum (1).
Numbers on curves indicate reflecting planes.

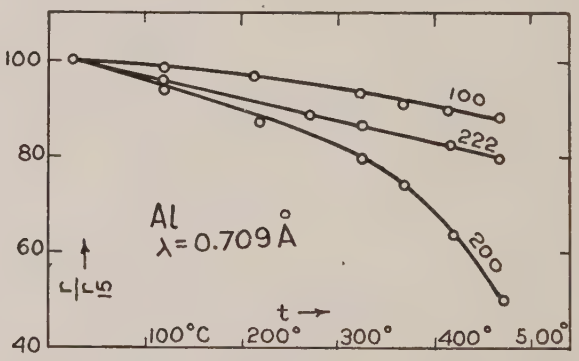

FIG. 2.—Variation of relative reflectivity with temperature: Aluminium (1).
Numbers on curves indicate reflecting planes.

NaCl (2); $\lambda = 0.614$; $t_1 = 15$; $t_2 = 370°$				Al Foil (4); $\lambda = 0.710$; $N = 1$; $t_1 = 80°$				
Pl	N	Obs.	Calc.	Pl	Obs.	Calc.	Obs.	Calc.
					$t_2 = 310°$		$t_2 = 600°$	
100	1	0.934	0.930					
110	1	0.833	0.862	100	0.88	0.966	0.815	0.926
100	2	0.794	0.741	110	0.77	0.935	0.56	0.857
110	2	0.483	0.526	111	0.92	0.973	0.86	0.936
100	3	0.515	0.521	311	0.84	0.913	0.709	0.809

C, Graphite (1); $\lambda = 0.709$; Pl = 0001; $a = 107$ if $t_1 = 0°$; $t_1 < t_2 < 900°$.

Al_2O_3, Ruby and sapphire (1); $\lambda = 0.709$; $t_1 = 15°$; $t_1 < t_2 < 950°$; $a_{110} = 52.6$; $a_{220} = 269$; $a_{222} = 309$; $a_{111} = 373$; $a_{333} = 426$. Subscripts indicate Pl.

TABLE 4.—REFLECTIVITY OF X-RAYS: EFFECT OF POLISH

Double spectrograph and successive reflections from two crystals. $r = 100\ I_2/I_1$, where $I_1[I_2]$ = intensity of beam incident upon [reflected by] the second crystal when so placed that the reflection is a maximum. First order reflection from planes 100 (*cf.* Fig. 3). $r_p[r_u]$ = value of r when crystals are polished [unpolished]. Unit of λ = 1 Å.

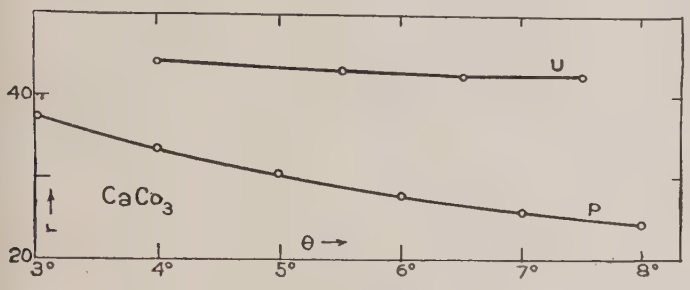

FIG. 3.—Effect of polishing: Calcite (9).
r = % reflected at glancing angle θ; P = polished; U = unpolished. λ = 0.317 to 0.842 Å, Pl = 100. (*Cf.* Table 4.)

TABLE 4.—(*Continued*)

λ	r_u	r_p	Lit.
	$CaCO_3$, Calcite		
0.369		35.4	(9)
0.422	44.4		(9)
0.580	43.1	29.2	(9)
0.685	42.8		(12)
0.790		25.3	(12)
	NaCl, Rock salt		
0.294	24.8	22.1	(10)
0.491	15.3	15.1	(10)
0.686	13.0	11.5	(12)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Backhurst, *5*, **102**: 340; 22. (2) Bragg and Bragg, *X-rays and crystal structure*, New York, Macmillan, 1918. (3) Bragg, James and Bosanquet *3*, **41**: 309; 21. **42**: 1; 21. (4) Collins, *2*, **24**: 152; 24. (5) Compton, *2*, **10**: 95; 17. (6) Compton, *3*, **45**: 1121; 23. (7) Darwin, *3*, **27**: 315; 14. (8) Davis and von Nardroff, *197*, **10**: 60; 24. (9) Davis and Stempel, *2*, **17**: 526; 21.
(10) Davis and Stempel, *2*, **19**: 504; 22. (11) Davis and Terrill, *197*, **8**: 357; 22. (12) Davis and Terrill, *3*, **45**: 463; 23. (13) Debye, *88*, **15**: 678, 738, 857; 13. (14) Hatley, *2*, **24**: 486; 24. (15) Larsson, Siegbahn and Waller, *218*, **12**: 1212; 24. (16) Lorentz, *Theory of electrons and its applications to the phenomena of light and radiant heat*. New York, Stechert, 1923. (17) von Nardroff, *2*, **24**: 143; 24. (18) Wagner and Kulenkampff, *8*, **68**: 369; 22,

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SYMBOLS

D Diameter of electrodes.
E Strength of electric field.
I Electric current.
l Length of arc.
R True resistance of arc: R = limiting values of dV/dI as dI approaches zero.
T Absolute temperature.
vp Vapor pressure.
V Voltage difference of electrodes.

Electrical Data.—The residual emf between cored carbon electrodes, after removal of impressed emf, is $\geq$ 0.64 volt at 0.4 sec and 0.05 volt at 7 sec (3). Duddell defines the counter emf as $V - RI$; for carbon arcs, he finds it varies from 11.2 to 18.5 volt, depending upon the current and the nature of the electrode (5, 10). Others have defined the term in various ways; hence the recorded values vary greatly (5).

Voltage Difference: Effect of Length and Current

$V = a + bl + cI^{-1} + dlI^{-1}$. Carbon (C) electrodes are solid unless the contrary is indicated. For metallic electrodes, I small, *see* (8). Unit of V = 1 volt, of I = 1 ampere, of l = 1 mm.

Electrodes	Gas	a	b	c	d	I	Lit.
Carbon*.....	Air	38.88	2.07	11.66	10.54	3 to 16	(2)
Carbon†.....	Air	0.0	0.99	0.0	0.0	120 to 700	(33)
Carbon‡.....	Air	62	11.4	0.0	3.26	3	(12)
Carbon.....	CO_2	80	1.17	90	7.3	3	(12)
Carbon.....	H_2	0.0	29	180	22.2	3	(12)
Carbon.....	H_2O	200	1.0	0.0	18.5	3	(12)
Carbon A. C.§		20.4	1.81	0.0	0.0	6.5	(15)
Magnetite....	Air	35.8	0.89	−7	5.81	3	(12)
Copper‖.....		18	17.5	52.1	3.43		(28)

* D = 11 mm; l measured from tip of cathode to plane through edges of crater; for long arcs, V is less than value given by these constants (10). For flaming arcs (6) and for cored carbons (20, 21), V is less than for solid carbons; no simple equation can be given for cored carbons (32).

† l measured from tip of cathode to bottom of crater.

‡ $l \leq 50$ cm.

§ Cored electrodes; A. C. = alternating current arc. *See also* note.*

‖ For metal electrodes, V varies greatly (6).

Distribution of Voltage

Determined by use of exploring electrodes. For small currents between metallic electrodes, *see* (8). $V_a[V_c]$ = drop of potential at anode [cathode]; anode = electrode of higher potential. Unit of V_a, V_c = 1 volt; of E = 1 volt/cm; of I = 1 ampere.

Electrode	Gas	V_a	V_c	E	I	Lit.
C, Carbon*.....	Air	33.7	8.96		10	(2)
Hg.....	Vacuum	4.08†	5.27 (27)	0.68‡	4.3	
Na-K.....	Vacuum	2.5	3.8	0.8	1.5	(23)

* Solid electrodes; l = 5 mm.

† vp = 0.45 mm Hg; value of V_a varies from 4.8 to 18, depending upon vp, I, and the shape of tube and electrodes (13); as vp and I are increased indefinitely V_a approaches 3.72 as limiting value (12, 24).

‡ vp = 2 mm Hg, T = 1000°K (2).

Mechanical Data.—Area of crater = 1.34 mm² per ampere for solid carbons (1); $= (3.83 + 1.52I)$ mm² for positive carbon cored, negative solid, and l = 4 mm, unit of I = 1 ampere (2).

Area of cathode spot = 0.0253 mm² per ampere for Hg-arcs (14); = 0.213 mm² per ampere for C-arcs of such lengths that anode does not affect the area and for I = 1.5 to 10 ampere (14).

Consumption of electrodes (unit of l = 1 mm). Solid carbons, open arcs, D = 1 cm, anode consumption if $l \geq 20$ mm is $(2.4 + 1.3l + 0.0044l^2)$ g per hr if I = 4 ampere, and $(1.73 + 0.086l + 0.003l^2)$ g per hr if I = 8 ampere; cathode consumption if $l \geq 12$ mm, I = 6 ampere, is $(0.72 + 0.022l - 0.0115l^2)$ g per hr (11).

Solid carbons, enclosed arcs, $D \equiv 11$ mm, $I = 5$ ampere, consumption of positive electrode = 1.65 mm per hr, of negative electrode = 0.319 mm per hr (21).

Flaming arc, carbon electrodes, anode D = 8 mm, cathode D = 7 mm, each electrode consumption = 30 mm per hr (26).

Magnetite arc, cathode consumption = 1.5 mm per hr (16), I = 6.6 ampere, value of D is not stated.

Temperature of the Arc.—The temperature of the cathode is usually several hundred degrees lower than that of the crater; that of the gases between the terminals is higher than that of the crater; the exact value is not known. The temperature of the crater of the carbon arc in air is between 3900 and 4000°K for graphite terminals (30); 4200°K at 1 atm., decreasing to 3940°K at 0.1 atm. for solid carbons (18, 19); 4200°K at 1 atm, increasing to 5890°K at 22 atm. for impregnated (cored) carbons (18, 19).

Photometric Data for Arcs

The luminous efficiency of the radiation (= ratio of energy of luminous radiation to that of total radiation) varies with l and I from 0.043 to 0.083 for direct current enclosed arcs between solid carbons, and from 0.115 to 0.225 for yellow flaming arcs, direct and alternating current (17).

V_t = voltage difference of lamp terminal; W = power expended in lamp; scp = mean spherical candlepower, lcp = mean lower hemispherical candle-power. Unit of I = 1 ampere; of V_t = 1 volt; of W = 1 watt; of scp, lcp = 1 candle.

Type	I	V_t	W	scp	W/scp	lcp	W/lcp	Lit.
Direct current arcs								
Carbon, open....	9.6	50	480	540	0.89	813	0.59	(25)
Carbon, enclosed	6.6	70 to 75	480	310	1.55	505	0.95	(25)
Flaming.....	8	44.2*	354	919	0.385	1670	0.21	(26)
Magnetite†.....	5	77.5	388	426	0.91			(9)
Alternating current arcs								
Carbon, enclosed	6.6	70	455	314	1.44			(22)
Flaming (Blondel).....	10	35*	255	1890	0.135			(4)

* Voltage difference of electrodes.

† With clear globe and small internal reflector.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Allen, *67*, **33**: 62; 21. (2) Ayrton, *The electric arc*. New York, Van Nostrand, 1902. (3) Becknell, *2*, **21**: 181; 05. (4) Blondel, *535*, **1904 II**: 731. (5) Child, *2*, **29**: 229; 09. (6) Child, *Electric arc*. New York, Van Nostrand, 1913. (7) Child, *2*, **12**: 277; 18. (8) Chrisler, *21*, **54**: 273; 21. (9) Cravath, *107*, **70**: 473; 17.

(10) Duddell, *62*, **203**: 305; 04. (11) Duffield, *5*, **92**: 122; 15. (12) Grotrian, *8*, **47**: 141; 15. (13) Günther-Schulze, *96*, **13**: 378; 23. (14) Günther-Schulze, *96*, **11**: 71, 74; 22. **31**: 509; 25. **37**: 868; 26. (15) Heubach, *101*, **13**: 460; 92. (16) Holmes, *107*, **43**: 1053; 04. (17) Karrer, *143*, **183**: 61; 17. (18) Lummer, *101*, **35**: 1116; 14. (19) Lummer, *121*, **75**: 517; 15.

(20) Marks, *121*, **31**: 502; 93. (21) Marks, *121*, **38**: 646; 96. (22) Matthews, *534*, **23**: 21; 00. **24**: 281; 01. **25**: 227; 02. *2nd Progress Report of the Committee for Investigating Photometric Values of Arc Lamps*, N. E. L. A., 1901. (23) Newmann, *3*, **47**: 603; 24. (24) Partzsch, *96*, **15**: 287; 23. (25) Ryan, *534*, **1**: 125; 85. (26) Solomon, *46*, **49**: 737; 12. *121*, **69**: 130; 12. (27) Stark, Retschinski and Schaposchnikov, *8*, **18**: 213; 05. (28) Steinmetz, *535*, **1904 II**: 710. (29) Upson, *3*, **14**: 126; 07.

(30) Waidner and Burgess, *31A*, **1**: 109; 04. (31) Waidner and Burgess, *2*, **19**: 241; 04. (32) Wehrli and Baumann, *96*, **38**: 35; 26. (33) Westman and Clapson, *78*, **44**: 137; 23.

THERMAL EMISSION OF ELECTRONS

SAUL DUSHMAN

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The relation connecting the absolute temperature (T) and the rate of electron emission is generally expressed in terms of I, the electric current per unit area of surface, by one or other of the equations $I = A_1 T^{0.5} e^{-b_1/T}$ and $I = A_2 T^2 e^{-b_2/T}$, which are experimentally indistinguishable within the temperature range covered in the past. In this range, $\frac{b_1 - b_2}{2.303} = \frac{3 \log_{10}(T_1/T_2)}{2(T_2^{-1} - T_1^{-1})}$ or approximately, $b_2 = b_1 - 1.5\frac{(T_1 + T_2)}{2}$, and $\log_{10}(A_1/A_2) = 1.5 \log_{10} T + (b_1 - b_2)/2.303T$ or approximately, $A_2 = 0.223 A_1 \times T^{-1.5}$. In general, data obtained before 1913–1914 are quite unreliable and even data obtained more recently are, in many cases, equally unreliable either because insufficient precautions were taken to secure a good vacuum or because a very inaccurate temperature scale was used. In a few cases in which very good data are available weighted average values are given in the following tables; these, and the individual values which are especially good, are each indicated by an asterisk (*). If W is the amount of work required to remove an electron from the surface, the "work function," $\phi = W/e$, is the potential difference required to confer upon an electron an amount of energy equal to W; $\phi = k_0 b/e = 8.62 \times 10^{-5} b$ volt. Unless the contrary is indicated the values of ϕ given in the following tables are derived from b_2, and will be denoted by ϕ_2. The relation between Richardson's ϕ_0 [28] and b_2 is $b_2 = 11\,600\phi_0$. Papers [12, 15, 32] should be read.

TABLE 1.—ELECTRON EMISSION AND THERMIONIC WORK FUNCTION: ELEMENTARY SUBSTANCES AND OXIDES

At temperature T, the current leaving the surface per cm² is $I_T = A_1 T^{0.5} e^{-b_1/T} = A_2 T^2 e^{-b_2/T}$; work function is ϕ. $A_1 = a_1 \times 10^n$, $A_2 = a_2 \times 10^n$, $b_1 = \beta_1 \times 10^4$, $b_2 = \beta_2 \times 10^4$, $I_T = i_T \times 10^n$. Unit of I = 1 ampere/cm² = 3×10^9 es/(sec cm²) = 0.1 em/(sec cm²) = 6.28×10^{18} electron/(sec cm²). Unit of ϕ = 1 volt = 10^8 cgsm unit of potential = 0.003335 cgse unit of potential = 1.591×10^{-12} erg per electron.

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T, °K	Lit.
Elementary substances											
C				6.02	1	4.65	4.00	2	− 2	2000	*
	7.45	6	5.49	1.86	1	5.19	4.48				(6, 28)
	2.37	6	4.87	5.93	0	4.57	3.93	2.84	− 3	2000	(20, 28)
			4.80			4.50	3.88				(22)
Ca	1.74	4	3.65	1.2	−1	3.50	3.02				(13, 28)
				6.02	1	2.60	2.24	4	− 3	1100	(7)
Ce on W†				8.0	0	3.15	2.72	5.8	− 2	1600	(8)
Cs				1.62	2	2.10	1.81	2.5	−11	500	(17)
Cs on W‡								1	− 4	700	(16, 23)
Cs on O on W†				<3.0	−3	0.830	0.72	3.5	− 1	1000	(16, 23)
Hf				4.75	4	5.91	5.09	2.6	− 2	2000	(43)
La on W†				8.0	0	3.15	2.72	5.8	− 2	1600	(8)
Mo; *see also* Table 2			5.26	6.02	1	5.15	4.44	1.59	− 3	2000	(10*)
			5.35	6.02	1	5.09	4.38	2.34	− 3	2000	(43*)
	2.1	7	5.00	6.1	1	4.74	4.08	1.3	− 2	2000	(19)
	1.1	8	5.36	3.23	2	5.10	4.39	1.12	− 2	2000	(28, 34)
Ni	4.61	6	3.40	2.68	1	3.21	2.77				(28, 30)
O on W†				5	11	10.70					(16, 23)
Pt (for effect of H, *see* [23])				6.02	1	5.90	5.08	1.6	− 8	1600	*
	1.195	7	4.93	5.38	1	4.73	4.08	2.2	− 4	1600	(26, 28)
	1.1	8	6.55	4.93	2	6.35	5.46	8	− 9	1600	(28, 39)
	1.86	8	7.25	8.40	2	7.05	6.05	1.8	−10	1600	(28, 39)
	7.96	9	6.78	3.56	4	6.58	5.68	1	− 7	1600	(27, 28)
	2.55	6	6.10	1.15	1	5.90	5.08	3	− 9	1600	(13, 28)
	4.87	6	6.10	2.19	1	5.90	5.08	6	− 9	1600	(6, 28)
	3.22	12	8.00	1.45	7	7.80	6.71	2.4	− 8	1600	(19, 28)
	1.15	7	5.11	5.16	1	4.91	4.23	5.6	− 6	1600	(28, 30)

Table 1.—(*Continued*)

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T, °K	Lit.
Elementary substances.—(*Continued*)											
Pt.—(*Continued*)	3.02	3	4.60	1.36	−2	4.40	3.87	4.5	− 8	1600	(25)
	9.90	3	5.20	4.46	−2	5.00	4.31	2.9	− 9	1600	(25)
				3.01	1	4.85	4.18				(29, 35)
	9.3	6	6.32	2.88	1	6.06	5.22	3	− 9		(33)
	7.59	8	5.79	Not gas-free§			4.99				(35)
	1.21	7	5.31	Less gas§			4.57				(35)
	9.7	8	5.84	In hydrocarbon vapors							(25)
Ta; *see also* Table 2		‖	4.98	6.02	1	4.72	4.07	1.38	− 2		(10)
	4.3	2	4.42	1.31	−3	4.17	3.58	4	− 6	2000	(6, 28)
	1.12	7	5.00	3.40	1	4.70	4.04	8.9	− 3		(19, 28)
	8.32	6	5.08	2.95	1	4.85	4.18	3.2	− 3		(33)
	1.19	5	3.64	Not gas-free§			3.14				(35)
	3.61	4	3.64	Less gas§			3.14				(35)
Th		‖		6.02	1	3.89	3.35	4.3	− 3	1600	(43)
Th on W†; *see also* Tables 2 and 4		‖		3.0	0	3.05	2.63	4.0	− 2	1600	(9*)
		‖		7.0	0	3.12	2.69				(16, 23)
U on W†				3.2	0	3.30	2.84	9.1	− 3	1600	(8)
W; *see also* Tables 2, 3, and 4				6.02	1	5.240	4.52	1.00	− 3	2000	*
			5.51	6.02	1	5.236	4.52	1.00	− 3	2000	(4)
	1.05	7	5.30	4.36	1	5.100	4.40	1.45	− 3	2000	(33)
			5.53	6.02	1	5.250	4.53	9.1	− 4	2000	(10)
			5.77	6.02	1	5.225	4.50	1.12	− 3	2000	(42, 43)
Yt on W†				7.0	0	3.13	2.70	5.8	− 2	1600	(8)
Zr				3.00	3	5.22	4.50	5.50	− 2	2000	(43)
Zr on W†				5.00	0	3.65	3.15	1.59	− 3	1600	(7)
Oxides on Pt											
Al_2O_3	6.61	6	4.85	1.62	1	4.63	3.90	5.9	− 2	2200	(33*)
	6.40	0	3.73	2.09	−5	3.48	3.00	6.2	− 7	1873	(14)
B_2O_3	5.37	6	5.45	1.32	1	5.23	4.51	3.1	− 3	2200	(33*)
BaO	6.6	5	2.15	2.88	0	1.95	1.68	3.55	− 1	1200	(33*)
	7.16	7	4.3			4.12					(37)
	4.70	7	4.16	2.72	2	3.99	3.44	2.78	− 6	1223	(14)
BaO + SrO	8 to 2.4	4 to 5	1.94 to 2.38			1.76 to 2.20	1.51 to 1.89	2.7 to 2.03	− 1 to − 3	1200	(1*)
				1.07	−3	1.21		6.45	− 2	1200	(18)
	In O_2, P = 0.005 mm			4.27	3	3.59					(18)
BeO	8.3	7	4.77	3.60	2	4.57	3.94	1.78	− 1	2000	(33*)
	1.03	0	2.39	4.56	−6	2.19	1.88	1.03	− 6	1373	(14)
CaO	2.05	7	3.12	1.29	2	2.92	2.52	2.19	− 1	1400	(33*)
	1.11	8	4.5			4.33					(37)
	6.36	11	4.8			4.62					(13)
	1.75	7	4.3			4.12					(6)
	4.30	7	4.03	2.49	2	3.86	3.33	1.83	− 6	1173	(14)
CdO	3.7	−1	3.02	1.65	−6	2.82	2.43	2.2	− 7	1673	(14)
CeO_2	1.95	3	3.71	8.62	−2	3.51	3.02	2.01	− 6	1523	(14)
Co_2O_3	6.67	3	4.97	2.17	−2	4.72	4.06	6.5	− 7	1723	(14)
CuO	3.5	−3	2.25	1.55	−8	2.05	1.76	2.2	− 7	1673	(14)
Fe_2O_3	3.57	3	4.69	1.16	−2	4.44	3.82	2.3	− 7	1723	(14)
La_2O_3	6.9	2	3.79	3.03	−3	3.59	3.10	2.01	− 6	1623	(14)
MgO	2.34	8	4.04	1.02	+3	3.84	3.31	1.02	− 1	1600	(33*)
	3.37	0	3.95	1.10	−5	3.70	3.19	1.0	− 7	1873	(14)
NiO	2.79	4	5.12	9.1	−2	4.87	4.19	1.5	− 7	1723	(14)
Sc_2O_3	5.50	6	4.31	1.35	1	4.09	3.52	7.2	− 2	2000	(33*)
SiO_2	3.80	6	5.74	1.23	1	5.50	4.75	8.5	− 4	2200	(33*)
SrO	9.3	5	2.36	4.07	0	2.16	1.86	8.5	− 2	1200	(33*)
	5.07	7	4.49	2.58	2	4.30	3.71	8.7	− 7	1273	(14)
	7.5	2	1.41	Anode potential = 200 volt							(11)
	2.4	3	1.44	Anode potential = 300 volt							(11)
ThO_2	1.78	5	3.93	5.7	−1	3.69	3.18	2.3	− 2	2000	(33*)
	3.5	1	3.56	1.54	−4	3.36	2.89	2.1	− 7	1573	(14)
TiO_2	6.31	5	5.16	2.04	0	4.92	4.24	1.2	− 3	2200	(33*)

TABLE 1.—(*Continued*)

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T,°K	Lit.
Oxides on Pt.—(*Continued*)											
Yt_2O_3	6.03	6	3.82	1.48	1	3.60	3.10	1.00	− 1	1800	(33*)
	1.86	4	3.63	8.22	−2	3.43	2.95	2.36	− 6	1373	(14)
ZnO	3.1	−1	3.51	1.0	−6	3.26	2.81	2.6	− 7	1973	(14)
ZrO_2	1.17	6	4.65	3.80	0	4.41	3.80	4.2	− 3	2000	(33*)
	6.57	3	3.66	2.90	−2	3.46	2.98	1.71	− 6	1423	(14)

Oxides on 95% Pt + 5% Ni (3)

Electrical resistivity of core = $2.2(10)^{-5}(1 + 0.00208t - 4.6(10)^{-7}t^2)$ ohm cm, t is centigrade temperature, °C. The coating is a mixture of the oxides of Ba and Sr plus a small admixture of Ni (and Pt) which is transferred from core to coating during preparation and activation of the filament. Thermal emissivity (ratio to black-body) = $0.4 + 2.5(10)^{-4}T$ if 800°K < T < 1200°K. Electron emission in zero field is given by $I_T = (10)^{-2}T^2e^{-11\ 600/T}$ ampere/cm². For anode potential = 150 volt and space-charge limited current = 0.010 ampere/cm², the average life is $1.5(10)^{-5}e^{22\ 000/T}$ hr. The following values are those most probable when anode potential = 150 volt and electric field is zero:

T	900	950	1000	1050	1100	°K
I_T	20	45	90	170	310	10^{-3} ampere/cm²
p_r¶	2.3	3.0	3.7	4.6	5.6	watt/cm²
p_e¶	0.02	0.045	0.09	0.17	0.31	watt/cm²
Life	730**	170**	55	20	7.4	10^3 hr

* This value is especially good. † Monatomic layer.
‡ Emission is a function of bulb temperature; bulb at 30°C.
§ These data are not very reliable.
‖ Values on this line should not be used if T > 1600°K.
¶ p_r = power thermally radiated; p_e = power absorbed by electron emission.
** Computed.

TABLE 2.—ELECTRON EMISSION FROM MO, TA, TH ON W, AND W: VARIATION WITH TEMPERATURE

Electric field is assumed zero; if, at cathode, $dV/dr > 0$, a correction must be applied, *see* (31); correction must be applied for losses in the leads, *see* (41). $I = i \times 10^n$ = current per unit area = $A_2T^2e^{-b_2/T}$ ampere/cm².

T, °K	Mo		Ta		Th on W		W	
	i	n	i	n	i	n	i	n
1 000	3.24	−15	1.95	−13	1.73	−7	1.07	−15
1 100	4.09	−13	1.71	−11	3.31	−6	1.52	−13
1 200	2.33	−11	7.21	−10	3.95	−5	9.73	−12
1 300	7.36	−10	1.73	− 8	3.27	−4	3.21	−10
1 400	1.41	− 8	1.23	− 7	2.03	−3	6.62	− 9
1 500	1.91	− 7	2.89	− 6	1.00	−2	9.14	− 8
1 600	1.89	− 6	2.44	− 5	4.06	−2	9.27	− 7
1 700	1.38	− 5	1.51	− 4	1.40	−1	7.08	− 6
1 800	8.32	− 5	7.94	− 4	4.28	−1	4.47	− 5
1 900	4.14	− 4	3.61	− 3	1.164	0	2.28	− 4
2 000	1.74	− 3	1.38	− 2	2.864	0	1.00	− 3
2 100	6.61	− 3	4.62	− 2			3.93	− 3
2 200	2.14	− 2	1.41	− 1			1.33	− 2
2 300	6.58	− 2	3.92	− 1			4.07	− 2
2 400	1.81	− 1	1.00	0			1.16	− 1
2 500	4.62	− 1	2.38	0			2.98	− 1
	A_2 = 60.2		A_2 = 60.2		A_2 = 3.0*		A_2 = 60.2	
	b_2 = 51 300		b_2 = 47 200		b_2 = 30 500*		b_2 = 52 400	

* These values should not be used for computing the emission of Th on W at T > 1600°K, approx.; *see* Table 4.

TABLE 3.—ELECTRON EMISSION BY W: EFFECT OF GASES (19, 28)

For effect of gas on other substances, *see* Table 1; $I = A_1T^{1/2}e^{b_1/T}$ ampere/cm²; $A_1 = a_1 \times 10^n$, $b_1 = \beta_1 \times 10^4$; P mm of Hg = pressure of the gas.

Gas	P	a_1	n	β_1
Vacuum	0.00007	1.62	−2	5.55
H_2	0.012	2.58	+2	8.25
	0.007	3.63	9	11.5
	0.0017	3.67	7	10.5
	0.0005	2.05	3	8.5

TABLE 2.—(*Continued*)

Gas	P	a_1	n	β_1
O_2		3.25	4	9.43
N_2*	0.002	1.05	1	7.32
		7.95	−1	6.82

* Effect for N_2 varies with anode voltage.

TABLE 4.—EMISSION OF ELECTRONS BY THORIATED W (9)

When W containing Th is heated, there is evaporation of Th from the surface and a diffusion of Th from the interior to the surface (*see* Table 5); the equilibrium condition is determined by the balancing of these two effects. If we write $\theta = (b_\theta - b_W)/(b_{Th} - b_W)$, where b_{Th} is the maximum value of b_2 for thoriated W, and b_W and b_θ are, respectively, the values of b_2 for W and for the thoriated W under study, then θ is, effectively, the fraction of the surface which is completely covered with Th. At temperatures above *ca.* 1600°K, the equilibrium value of θ is <1, and decreases as T increases (21). Kingdon (16, 23) states $b_\theta = 31\ 200\theta + 52\ 200(1 - \theta)$ and $A_2 = [7^\theta + 60^{(1-\theta)} - 1]$ ampere/(cm² deg²). $I_T = A_2T^2e^{-b_2/T}$ ampere/cm² = $i \times 10^n$; $b_2 = \beta_2 \times 10^4$.

θ	$\log_{10} A_2$	β_2	$\log_{10} I$*	i*	n
1	0.455	3.040	0.066	1.16	0
0.924	0.397	3.213	$\bar{1}$.613	4.19	−1
0.830	0.318	3.415	$\bar{1}$.072	1.18	−1
0.723	0.573	3.657	$\bar{2}$.775	5.96	−2
0.565	0.890	4.007	$\bar{2}$.292	1.96	−2
0.440	1.036	4.284	$\bar{3}$.804	6.37	−3
0.250	1.199	4.705	$\bar{3}$.037	1.09	−3

* For T = 1900°K.

TABLE 5.—DIFFUSION AND EVAPORATION OF ELEMENTS CONTAINED IN W AS OXIDES (8)

D cm²/sec = diffusivity; E atoms/(cm² sec) = rate of normal evaporation of the element from the surface of the W; H_d g-cal = heat of diffusion = quantity of heat required to produce the diffusion of 1 g-atom of the diffusing material through the metal (here W) in which it is contained. $D = d \times 10^{-11}$; $E = e \times 10^9$; $H_d = h \times 10^3$; T = 2000°K.

TABLE 5.—(*Continued*)

	d	*e*	*h*
Ce	95	1450	83
Th*	5.9	1.53	94
U	1.3	>Th	100
Yt	1820		62
Zr	324	68	78

* Langmuir[21] finds for Th, $\log_{10} D = 0.044 - 20\,540/T$; $\log_{10} E = 31.434 - 44\,500/T$.

TABLE 6.—THERMIONIC WORK FUNCTION (ϕ): CALORIMETRIC DETERMINATION

ϕ_c = value by calorimeter, ϕ_b = value computed from b_2 (from b_1, in case of [40]); same material for each. Unit of ϕ = 1 volt = 1.591×10^{-12} erg per electron.

Elementary substances				Oxides on Pt					
Material	ϕ_c	ϕ_b	Lit.	Oxides			ϕ_c	ϕ_b	Lit.
				Ba	Ca	Sr			
C	4.55		[24]						
Mo*	4.59		[24]	50	25	25	2.39	2.34	[40]
Os	4.7		[2]				2.54	2.59	
Pt	5.9		[38]	50	0	50	1.97	2.02	[40]
Ta	4.51		[24]				2.28	2.16	
W	4.52	4.52	[4]	(?)	0	(?)	1.61	1.65	[5]
	4.48		[24]	0	100	0	3.22	3.28	[40]

* Effect of gas, Mo at 200°C [36]: A, ϕ_c = 4.76; H_2 + A, ϕ_c = 4.04 to 4.35; N_2, ϕ_c = 4.77 to 5.01.

Electron emission data for fused gold, silver and copper above and below the melting point have been measured by Goetz [12]. Values of A and b vary with the temperature. For a comprehensive discussion of theory and data, *see* W. Schottky and H. Rothe, *Physik der Glühelektroden, Handbuch der Experimentalphysik*, **13 II**, Leipzig, 1928.

LITERATURE

(For a key to the periodicals see end of volume)

[1] Arnold, *2*, **16**: 70; 20. [2] Cooke and Richardson, *3*, **25**: 624; 13. [3] Davisson, 463 West St., New York City, *0*. [4] Davisson and Germer, *2*, **20**: 300; 22. [5] Davisson and Germer, *2*, **24**: 666; 24. [6] Deininger, *8*, **25**: 285; 08. [7] Dushman, *2*, **21**: 623; 23. [8] Dushman, Dennison and Reynolds, *2*, **29**: 903; 27. [9] Dushman and Ewald, *2*, **29**: 857; 27.
[10] Dushman, Rowe, Ewald and Kidner, *2*, **25**: 338; 25. [11] Espe, *Wiss. Veröffentlich. Siemens-Konzern*, **5**: No. 3, 29; 27. [12] Goetz, *96*, **43**: 531; 27. [13] Horton, *62*, **207**: 149; 07. [14] Jentzsch, *8*, **27**: 129; 08. [15] King, *Bell System Tech. J.*, **2**: No. 4, 31; 23. [16] Kingdon, *2*, **24**: 510; 24. [17] Kingdon, *2*, **25**: 892; 25. [18] Koller, *2*, **25**: 671; 25. [19] Langmuir, *2*, **2**: 450; 13. *63*, **15**: 516; 14.
[20] Langmuir, *78*, **29**: 125; 16. [21] Langmuir, *2*, **22**: 357; 23. [22] Langmuir, *in B89*. [23] Langmuir and Kingdon, *5*, **107**: 61; 25. [24] Lester, *3*, **31**: 197; 16. [25] Lockrow, *2*, **19**: 97; 22. [26] Richardson, *62*, **201**: 497; 03. [27] Richardson, *3*, **207**: 1; 06. [28] Richardson, *B89*. [29] Roy, *512*, **9**: 61; 24.
[30] Schlichter, *8*, **47**: 573; 15. [31] Schottky, *63*, **15**: 872; 14. [32] Schumacher and Harris, *1*, **48**: 3108; 26. [33] Spanner, *8*, **75**: 609; 24. [34] Stoekle, *2*, **8**: 534; 16. [35] Suhrmann, *96*, **13**: 17; 22. [36] Van Voorhis, *2*, **30**: 318; 27. [37] Wehnelt, *8*, **14**: 425; 04. [38] Wehnelt and Liebreich, *88*, **15**: 1057; 13. *63*, **15**: 548; 14. [39] Wilson, *62*, **202**: 243; 03.
[40] Wilson, *2*, **10**: 79; 17. *197*, **3**: 426; 17. [41] Worthing, *143*, **194**: 597; 22. [24] Zwikker, *208*, **5**: 249; 25. [43] Zwikker, *64P*, **29**: 792; 26.

CONTACT POTENTIALS

SAUL DUSHMAN

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Data from photoelectric effect (illustrative).
Data from thermal emission of electrons (illustrative).
Contact potentials.
Metals with brass: condenser method.
Metals with platinum.
Miscellaneous pairs of conductors: condenser method.
Dielectrics in contact with Hg and amalgams.

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Daten aus dem photoelektrischen Effekt (erläuternd).
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Kontaktpotentiale.
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If the heat absorbed when one unit of electricity passes (1) from the free surface of conductor A to the free surface of conductor B, in contact with A, is P'_{AB}; (2) across the junction from A to $B = P_{AB}$; (3) from surface of A [B] to infinity $= P_{AS}$ [P_{BS}]; then $P'_{AB} = P_{AB} - P_{BS} + P_{AS}$. Let $K_{AB} = V_A - V_B$ = contact potential of A with reference to B; V_A, V_B are the simultaneous potentials of A, B when in contact [2, 5]. From thermodynamics, it follows that $dK_{AB}/dT = -P'_{AB}/T$; for Fe and Ni this amounts to 0.000032 volt/degree at 50°C, while the experimental value for the range 20 to 60°C is 0.0016 volt/degree [5]. The discrepancy is ascribed to the formation of a thin surface layer of oxide.

The value of K_{AB} may be deduced from data pertaining to the thermo- and photo-emission of electrons. If I = current per unit area carried by the thermoelectrons, $K_{AB} = \frac{k_0 T}{e} \log_e \frac{I_A}{I_B}$, and if $I = AT^n e^{-\phi e/k_0 T}$ (*cf.* p. 53), $K_{AB} = \phi_B - \phi_A + \frac{k_0 T}{e} \log_e \frac{A_A}{A_B}$.

If A is a universal constant [18], $K_{AB} = \phi_B - \phi_A$.

If ν_0 = threshold frequency for emission of photoelectrons, V_{rAa} = retarding voltage = potential to which A must be raised above the anode in order to prevent the emission of photoelectrons under action of radiation of frequency ν, and K_{Aa} = contact potential of A with reference to anode, then [12, 15] $(V_{rAa} + K_{Aa})e = h(\nu - \nu_{0A})$ and $K_{AB} = V_{rBa} - V_{rAa} + (\nu_{0B} - \nu_{0A})h/e = V_{rBa} - V_{rAa} + (\phi_B - \phi_A)$; this equation is confirmed by experiments [9, 15]. Millikan [15] calls $(V_{rBa} - V_{rAa})$ the "spurious" and $(\nu_{0B} - \nu_{0A})h/e$ the "intrinsic" contact potential. For clean metals $V_{rBa} = V_{rAa}$; for others the equality may fail [15]. Comparing this expression for K_{AB} with that derived from thermoelectronic data, it is obvious that $V_{rBa} - V_{rAa} = \frac{k_0 T}{e} \log_e \left(\frac{A_A}{B_B}\right)$, if ϕ denotes the same quantity in each case [18].

Many of the following data are not very reliable, but those obtained under similar conditions probably indicate the correct order of the conductors in a Volta series.

TABLE 1.—VALUES OF THE WORK FUNCTION (ϕ) AS DERIVED FROM THE WAVE-LENGTH LIMIT (λ_0) OF THE PHOTOELECTRIC EFFECT: ILLUSTRATIVE DATA

Values for other substances may be derived from the photoelectric data on pages 67–69.

$\phi = \frac{hc}{e\lambda_0}$; $K_{AB} = V_{rBa} - V_{rAa} + \phi_B - \phi_A = \frac{k_0 T}{e} \log_e \frac{A_A}{A_B} + \phi_B - \phi_A$ where A_A and A_B have the values derived from thermal electron emission data, p. 53. For clean surfaces, $K_{AB} = \phi_B - \phi_A$. $\phi/\nu_0 = 4.117 \times 10^{-15}$ (volt sec); $\phi\lambda_0 = 12\,344$ (volt Ångstrom). Unit of $\lambda_0 = 1$ Å $= 10^{-8}$ cm $= 10^{-4}\mu$; of $\phi = 1$ volt $= 10^8$ cgsm unit $= 3.33 \times 10^{-3}$ cgse unit.

Conductor	λ_0	Lit.	ϕ	Conductor	λ_0	Lit.	ϕ
Li	5263	(14)	2.35	Pt	2570	(11)	4.80
Na	5770	(6)	2.14		2910	(19)	4.24
	to		to		2960	(21)	4.17
	5830		2.12	Ta	3283	(21)	3.76
	6800	(13)	1.82	W	2200	(7)	5.61
	4860	(21)	2.54		3062	(21)	4.03
				BaO, SrO*	2860†	(11)	4.31
					3800‡	(11)	3.24

* On Pt. †At 20°C. ‡ At 420°C.

TABLE 2.—CONTACT POTENTIAL DEDUCED FROM THERMAL EMISSION OF ELECTRONS

Data for other pairs of conductors may be computed from the data on pages 55–56, by the relation $K_{AB} = \phi_B - \phi_A + \frac{k_0 T}{e} \log_e \frac{A_A}{A_B}$. All data from (22) refer to metals in vacuum. $K_{AB} = V_A - V_B$. Unit of $K_{AB} = 1$ volt.

A	B	K_{AB}	Lit.
Al	C	+0.87	(22)
C	C-black*	−0.24	(22)
C	Fe	−0.02	(22)
C-black*	W	+0.36	(22)
Fe	W	0.00	(22)
W	Zn	−0.51	(22)
W_{hot}	Cu_{cold}	†	(20)
Pt_{hot}	Pt_{cold}	+0.16‡	(20)
Th W_{hot}§	W_{cold}	+0.71	(20)

* Lampblack.
† Presence of H_2 makes W more positive; Hg vapor has no effect.
‡ In H_2, pressure = 0.112 mm of Hg; temp. of Pt_{hot} = 1460°K.
§ Th W = Thoriated W.

TABLE 3.—CONTACT POTENTIAL OF METALS WITH BRASS: CONDENSER METHOD; ROOM TEMPERATURE

Values tabulated are the differences $V_{metal} - V_{brass}$ columns (1), (2), (3); metal in vacuum; (1) surface freshly scraped; (2) four days after scraping; (3) before scraping. Column (4) metal in air at atmospheric pressure; (5) in air at pressure of 0.0001 mm; (6) highest value obtained after heating to high temperature in vacuum; (7) in air at atmospheric pressure; (8) in air at room temperature and atmospheric pressure. Unit of potential = 1 volt $= 10^8$ cgsm unit $= 3.33 \times 10^{-3}$ cgse unit.

Metal	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ag	+0.05	0	−0.097				−0.35	−0.286
Al	+1.04	+0.874	+0.293	+0.19*	+0.20*	+0.90*		+0.670
Au				−0.23	−0.22	+0.02	−0.33	−0.269
Bi							+0.07	
Cu	+0.10	−0.110	−0.106	−0.04*	−0.04*	+0.44*	−0.15	−0.154
Fe	+0.24	+0.192	+0.053				0.00†	+0.040
Mg	+1.47	+0.713	+0.825					
Ni				+0.16	+0.18	+0.47	+0.09	
Pb							+0.41	+0.396
Pt				−0.30*	−0.28*	−0.23*	−0.32	−0.354
Sb							+0.15	
Sn	+0.32	+0.317	+0.216					+0.318
Zn	+0.64	+0.496	+0.193	−0.596‡			+0.43*	+0.608
Brass	+0.26	+0.228	−0.123					
Lit.	(8)	(8)	(8)	(26)	(26)	(26)	(16)	(1)

* Mean of observations on 2 different specimens. † Same for steel.
‡ One hr after polishing; 1 week after polishing found −0.543; both surfaces polished (23).

TABLE 4.—CONTACT POTENTIAL (K) OF METALS WITH PLATINUM (19)

$K = V_{metal} - V_{Pt}$; unit = 1 volt $= 10^8$ cgsm unit $= 3.33 \times 10^{-3}$ cgse unit

Metal	Al	Bi	Cu	Mg	Na	Sn	Zn
K	1.20	0.35	0.13	1.05	2.40	0.62	0.90

TABLE 5.—CONTACT POTENTIALS OF MISCELLANEOUS PAIRS OF CONDUCTORS: CONDENSER METHOD; ROOM TEMPERATURE

For metals with brass, *see* Table 3; $K_{AB} = V_A - V_B$

A	B	K_{AB}	Lit.	A	B	K_{AB}	Lit.
Al*	Fe	+0.87	(4)	Pt	Zn‖	‖	(10)
Al*	Zn	+0.29	(4)	K	Pt	+2.8	(25)
Fe*	Zn	−0.60	(4)	C + NH_3¶	Cu	+0.079	(24)
CuO*	Li	−1.52†	(14)	C + H_2¶	Cu	+0.096	(24)
		−1.11‡	(14)	C + N_2¶	Cu	+0.129	(24)
CuO*	Na	−2.52	(14)	C + CO_2¶	Cu	+0.130	(24)
Cd§	Hg	−0.22	(17)	C + NO¶	Cu	+0.136	(24)
Hg§	Sb	−0.26	(17)	C + O_2¶	Cu	+0.142	(24)
Hg§	Zn	+0.17	(17)	C + O_3¶	Cu	+0.155	(24)
Bi‖	Pt	‖	(10)				

* In vacuum. † Fresh surface. ‡ Old surface.
§ Initial value in dry air, pressure = 0.05 mm Hg. K_{AB} varies with the time. Author also gives data for moist air, H_2 and CO_2.
‖ Distilled in vacuum; initially K_{AB} is low, traces of air cause the Bi and Zn to become more positive; after passing a maximum, an equilibrium value is approached. ¶ Coconut charcoal saturated with the gas indicated.

TABLE 6.—SIGNS OF CHARGES ACQUIRED BY DIELECTRICS IN CONTACT WITH HG AND WITH AMALGAMS (3)

Surfaces in high vacuum

Dielectric	Hg	Ag-Hg	Na-Hg	Zn-Hg
Amber	−	−	+	+
Diamond, C	−	−	−	−
Ebonite	−	−	+	+
K-glass	−	−	+	−
Na-glass	−	−	+	+
Sealing wax	−	−	+	+
Quartz, SiO_2	−	−	+	+

LITERATURE

(For a key to the periodicals see end of volume)

(1) Anderson and Bowen, *67*, **23**: 346; 11. (2) Bridgman, *2*, **14**: 306; 19. (3) Coehn and Curs, *96*, **29**: 186; 24. (4) Compton, *3*, **23**: 579; 13. (5) Compton, *2*, **7**: 209; 16. (6) Compton and Richardson, *3*, **26**: 549; 13. (7) Hagenow, *2*, **13**: 415; 19. (8) Hennings, *2*, **4**: 228; 14. (9) Hennings and Kadesch, *2*, **8**: 209; 16.
(10) Hughes, *3*, **28**: 337; 14. (11) Koppius, *2*, **18**: 443; 21. (12) Langmuir, *78*, **29**: 125; 16. (13) Millikan, *2*, **4**: 73; 14. (14) Millikan, *2*, **7**: 18; 16. (15) Millikan, *2*, **18**: 236; 21. (16) Pellat, *6*, **24**: 5; 81. (17) Perucca, *34*, **173**: 551; 21. (18) Richardson, *Electron theory of matter*. London, Cambridge Univ. Press, 1916. (19) Richardson and Compton, *3*, **24**: 575; 12.
(20) Richardson and Robertson, *3*, **43**: 162, 557; 22. (21) Roy, *512*, **9**: 61; 24. (22) Schottky, *3*, **44**: 1011; 14. (23) Shaw, *3*, **25**: 242; 13. (24) Stuhlmann, *2*, **8**: 294; 16. (25) Thirring, *63*, **14**: 406; 13. (26) Vieweg, *3*, **74**: 146; 24.

CURRENT FLOW IN VACUUM TUBES WITH HOT CATHODES

ALBERT W. HULL

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In what follows it is assumed that the emission of electrons (or ions) from the cathode (*see* p. 53) is so ample that the current through the tube is not limited by it.

Diodes.—If the carriers are emitted with velocity = 0, then in all cases $i = KGV_a^{1.5}$, where the value of KG depends only upon the construction of the tube and upon the system of units employed. K depends upon e/m and G upon certain ratios determined by the geometrical configuration of the conductors in the tube; G is dimensionless. Except in certain ideal cases, KG is treated as a single quantity and is denoted by k (*see* Table 3).

Triodes (10, 22).—If the carriers are emitted with velocity = 0, and if there is no magnetic field, $i(= i_p + i_g) = k(E_p + \mu E_g)^{1.5}$, approximately, *see* (20); k has the same value as for the corresponding diode; μ depends solely upon the geometrical configuration of the conductors in the tube (1, 4, 17, 20), but by varying the size of the grid mesh, it can be given any desired value. The mutual conductance (g_m) is a function of i_p, but for a given value of i_p, it is nearly independent of size of grid mesh. It is roughly proportional to length of cathode filament and inversely proportional to distance between grid and filament (*see* Table 4).

Tubes with Four Electrodes.—Space-charge grid tubes have the second grid next to the filament; the presence of this grid multiplies g_m by approximately 4, but the other constants remain the same as for the corresponding triode (21). Screen-grid tubes have the second grid between grid and plate. If screening is perfect, i_p is a function of E_g only, and the value of g_m is only about ¾ as great as in the corresponding triode (7, 21).

SYMBOLS

A	Area of one side of a plate electrode
$\mathbf{c}$	Velocity of light *in vacuo*.
cgse	Cgs electrostatic system of units.
cgsm	Cgs electromagnetic system of units.
csva	Cm-sec-volt-ampere system of units, absolute volt and ampere.*
csVA	Cm-sec-volt-ampere system of units, international volt and ampere.*
E_p, E_g	Potential of plate, grid, above that of cathode.
$\mathbf{e}$	Negative electronic charge.
e	Negative charge of the carrier of electricity (electron or ion).
G	Geometrical factor of k.
g_m	Mutual conductance of plate and grid, $g_m = -\partial i_p/\partial E_g$, E_p being constant.
H	Strength of magnetic field externally applied parallel to axis of cylindrical electrodes.
I	Current flowing through the inner cylindrical electrode parallel to its axis.
i, i_p, i_g	Current to cathode: Total, from plate, from grid; $i = i_p + i_g$.
K	Physical factor of k.
k_0	Boltzmann gas constant.
k	Space charge constant characteristic of the tube; $k = KG$.
l	Length of cylindrical electrode.
M	Molecular weight of the carrier ions.
m	Mass of the carrier of electricity (electron or ion).
$\mathbf{m}_0$	Mass of negative electron at low velocity.
r_a, r_c	Radius of anode, cathode.
r_o, r_i	Radius of outer, inner, of two coaxial cylinders, or of two concentric spheres.
R_p	Plate resistance; $R_p = 1/(\partial i_p/\partial E_p)$, E_g being constant.
T	Absolute temperature of the carriers of electricity, °K. For thermionic carriers, T = temperature of cathode (3); for electrons from low pressure arcs, T is nearly independent of current density, but depends upon the nature and pressure of the gas, and ranges from 10 000 to 50 000°K (16).
V	Excess of potential above that of cathode.
V_m	Minimum value of V in space between anode and cathode.
V_a	Potential of anode above that of cathode.
v	Velocity of carrier.
v_i	Initial velocity of carrier.
x	Distance from cathode in direction of anode.
x_m	Value of x corresponding to V_m.
x_a	Distance between anode and cathode.
α^2, β^2	Functions of r_o/r_i.
ϵ	Dielectric constant of a vacuum. In cgse system, $\epsilon = 1$; in cgsm, $\epsilon = \mathbf{c}^{-2}$; in csva, $\epsilon = (10)^9\mathbf{c}^{-2}$; in csVA, $\epsilon = 1.00052(10)^9\mathbf{c}^{-2}$.
μ	Amplification factor; $\mu = -dE_p/dE_g$, i_p being constant.

* In csva system, unit of mass is 10^7 g; required by relation $eV = \frac{1}{2}mv^2$. In csVA system, unit of mass is $\frac{10^7}{1.00032}$ g.

TABLE 1.—IDEAL DIODES

K_e = value of K if carriers are electrons; $K = K_e\sqrt{e\mathbf{m}_0/\mathbf{e}m} = K_e\sqrt{e/(1847M\mathbf{e})}$. ‖ Plates, Coax. Cyl., Con. Sph. = parallel plates, coaxial cylinders, concentric spheres. General formulae are valid for any consistent system of units; a numerical value is valid only for the indicated system of units.

Electrodes	G	Formula, K	cgse k_e	cgse n	csVA k_e	csVA n	Lit.
Magnetic field = 0, $v_i = 0$; $i = KGV_a^{1.5}$; $K_e \equiv k_e \times 10^n$							
‖ Plates...	$\frac{A}{x_a^2}$	$\frac{\sqrt{2}}{9\pi}\epsilon\sqrt{\frac{e}{m}}$	3.643	+7	2.341	−6	(2, 8, 11)
Coax. cyl...	$\frac{l^*}{r_a\beta^2}$	$\frac{2\sqrt{2}}{9}\epsilon\sqrt{\frac{e}{m}}$	22.89	+7	14.71	−6	(13, 15)
Con. sph...	$\frac{1^*}{\alpha^2}$	$\frac{4\sqrt{2}}{9}\epsilon\sqrt{\frac{e}{m}}$	45.78	+7	29.42	−6	(14)
Magnetic field = 0, v_i has a Maxwellian distribution (12)							
‖ Plates...	$i = GK(V_a - V_m)^{1.5}\left(1 + C\sqrt{\frac{T}{V_a}}\right)$, where K has same value as for $v_i = 0$, $G = A/(x_a - x_m)^2$, and $C = 2.66\sqrt{\frac{k_0}{e}}$. If $e = \mathbf{e}$, then $C = 0.001426$ cgse $= 0.0247$ csVA.						
Magnetic field $\neq 0$, $v_i = 0$							
Coax. cyl..	$i = GKV_a^{1.5}$ if $V_a > V'$; $i = 0$, if $V_a < V'$. G and K have same values as for field = 0; $V' = \frac{e}{m} \times \left[\frac{H^2r_o^2}{8} + 2I^2\left(\log_e\frac{r_o}{r_i}\right)^2\right]$. In the csVA system, $V' = 0.0221H^2r_o^2 + 0.0188I^2\left(\log_{10}\frac{r_o}{r_i}\right)^2$, if carriers are negative electrons.						

* For values of α^2 and β^2, *see* Table 2.

TABLE 2.—VALUES OF COEFFICIENTS α^2 AND β^2

For coaxial cylinders, $G = l/(r_a\beta^2)$; for concentric spheres, $G = 1/\alpha^2$ (*see* Table 1)

Cathode,	Inside	Outside	Inside	Outside
r_o/r_i	α^2 (14)		β^2 (13)	
1.1	0.0086	0.0096	0.0001	0.01
1.5	0.1302	0.2118	0.1193	0.228
2.0	0.326	0.750	0.2793	0.845
3.0	0.669	2.512	0.5170	2.98
4.0	0.934	4.968	0.6671	6.06
5.0	1.141	7.98	0.7666	9.89
10	1.777	29.2	0.9782	37.0
20	2.378	93.2	1.0715	115.6
50	3.120	395	1.0936	450.2
100	3.652	1 144	1.0782	1 175
200	4.166	3 270	1.0562	2 946
500	4.829	13 015	1.0307	9 502
1 000	5.328		1.0171	
∞			1.0000	

TABLE 3.—CHARACTERISTICS OF TYPICAL COMMERCIAL DIODES (6)

In all cases $i = kV_a^{1.5}$ (9). The tubes are so constructed that, for the size of anode used, k is as great as is now (Jan., 1927) considered practical. The values are for American tubes, but do not differ appreciably from those for similar tubes constructed elsewhere. i_f, E_f = filament current, voltage; E_m = maximum effective A.C. input voltage; i_m = maximum rectified tube current; P_n = nominal power rating; ThW, PW = thoriated tungsten, pure tungsten, filament. Unit of i_f and i_m = 1 ampere; of E_f and E_m = 1 volt; of P_n = 1 kilowatt; of k = 0.0001 ampere/volt$^{1.5}$.

Type	i_f	E_f	E_m	i_m	P_n	k
ThW.....	1.25	7.5	550	0.065	0.0075	1.2
ThW.....	3.25	10	1 500	0.20	0.050	1.7
ThW.....	3.85	11	2 500	0.25	0.250	1.1
PW.....	14.7	11	16 000	0.166	1.00	0.5
PW.....	24.5	22	17 500	0.833	5.00	1.0
PW.....	52	22	18 000	3.0	20.00	1.1
PW.....	10	10	20 000	0.10		0.10
PW.....	10	10	85 000	0.10		0.11
PW.....	32	9	75 000	0.25		0.25
PW.....	10	10	150 000	0.100		0.11
PW.....	32	12.5	150 000	0.25		0.11

TABLE 4.—CHARACTERISTICS OF TYPICAL COMMERCIAL TRIODES

The following data for American tubes differ but little from those for corresponding tubes manufactured elsewhere. Ox, ThW; PW = oxide coated, thoriated tungsten, pure tungsten filaments; i_f = filament current, E_f filament voltage; E_p = normal plate voltage, L, D = overall length, diameter, of tube; P_a = safe continuous energy dissipation at anode; P_o = rated power output; E_g, i_p = grid voltage, plate current, for normal operation as amplifier. Unit of i_f = 1 ampere; of i_p = 0.001 ampere; of E_f, E_p, E_g = 1 volt; of L, D = 1 cm; of P_a, P_o = 1 kilowatt; of g_m = 0.001 mho = 0.001 ohm^{-1}. μ is dimensionless.

Standard American Triodes (18, 19)

Type	i_f	E_f	L	D	R.C.A. name	E_p	E_g	i_p	g_m	μ	P_a	P_o
Ox.....	0.25	1.1	10	3.0	WD11	90	− 4.5	2.5	0.425	6.6		
Ox.....	0.25	5.0	12	4.6	UX112-A	135	− 9	10.0	1.70	8.0		
ThW.....	0.06	3.0	10	3.0	UX199	90	− 4.5	2.5	0.425	6.6		
ThW.....	0.125	3.0	10	3.0	UX120	135	− 22.5	6.5	0.500	3.3		
ThW.....	0.50	5.0	12	4.6	UX171	180	− 40.5	20	1.500	3.0		
						135	− 27	17	1.360	3.0		
ThW.....	0.25	5.0	12	4.6	UX201-A	135	− 9	3.0	0.800	8.0		
						90	− 4.5	2.5	0.725	8.0		
ThW.....	0.25	5.0	12	4.6	UX240	135	− 1.5	0.20	0.200	30.0		
ThW.....	1.25	7.5	14	5.5	UX210	425	− 35	20	1.500	7.5		
ThW.....	3.25	10	20	5.4	UV203-A	1 000	0	120	5	25	0.10	0.075
ThW.....	3.85	11	36	10	UV204-A	2 000	0	300	5	25	0.25	0.25
ThW.....	15.5	11	45	15	UV851	2 000	− 60	350	15	20	0.750	1
PW.....	14.75	11	40	12.5	UV206	15 000	0	54	1.9	325	0.35	1
PW.....	24.5	22	57	15	UV208	15 000	0	195	3.2	240	1.0	5
PW.....	52	22	48	11	UV207	15 000	−475	400	4.5	20	10	20

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abraham, *125*, **8**: 42; 20. (2) Child, *2*, **32**: 492; 11. (3) Davisson and Germer, *2*, **20**: 300; 22. (4) Eccles, *540*, **1**: 67; 19. (5) Hull, *2*, **18**: 31; 21. (6) Hull, *2*, **25**: 645; 25. (7) Hull and Williams, *2*, **27**: 432; 26. (8) Langmuir, *2*, **2**: 450; 13. (9) Langmuir, *63*, **15**: 348; 14. (10) Langmuir, *529*, **3**: 261; 15. (11) Langmuir, *120*, **26**: 731; 23. (12) Langmuir, *2*, **21**: 419; 23. (13) Langmuir and Blodgett, *2*, **22**: 347; 23. (14) Langmuir and Blodgett, *2*, **24**: 49; 24. (15) Langmuir and Kingdon, *166*, **57**: 58; 23. (16) Langmuir and Mott-Smith, *120*, **27**: 449; 24. (17) von Laue, *8*, **59**: 465; 19. (18) Radio Corpn. of America, *Standard power radiotrons and rectrons;* 1928. (19) Radio Corpn. of America, *Bull.*, Nov. 21, 1927.
(20) Schottky, *125*, **8**: 1; 20. (21) Schottky, *125*, **8**: 299; 20. (22) Whittemore, *529*, **14**: Suppl.; 1926.

EMISSION OF SECONDARY ELECTRONS

H. E. Farnsworth

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The electrons and positive ions incident upon the substance under consideration are designated as "primary;" those leaving it, as "secondary." Generally the secondary electrons which result from impact of electrons are of two distinct classes: (*a*) those which have velocities of the same order as that of the primaries, and (*b*) those with much smaller velocities. The former are regarded as primary electrons which have been reflected [transmitted] by the substance; the latter, as electrons which originated in the substance.

SYMBOLS

See also Vol. I, p. 16

c	Velocity of light.
d	Density.
N	Number of secondary electrons per primary electron or +ion.
n	Number of secondary electrons.
V_v, V_{vp}, V_{vx}	Retarding potential difference required to stop an electron which has the velocity v, v_p, v_x.
v, v_p, v_x	Velocity of the electrons, of the primary electrons, of electrons at point x.
Δ	$v_p - v_x$.
δ_θ	$[(N_t)_\theta - (N_t)_0]/(N_t)_0$.
r	Thickness.
θ	Angle of incidence.
φ	Angle of emergence; like θ, φ is measured from the normal.

Subscripts of special significance

f	Fast electrons, velocity of same order as v_p.
s	Slow electrons, velocity much less than v_p.
t	Total electrons of all velocities.
p	Primary electrons.
1[2]	Electrons from 1st [2nd] surface of thin film; the 1st surface is the surface of incidence.

TABLE 1.—RETARDING POTENTIAL DIFFERENCE REQUIRED TO BRING AN ELECTRON TO REST: EINSTEIN'S RELATION

v = initial velocity of the electron, V_v = potential difference required to reduce the velocity from v to 0. Einstein's relation is

$$V_v = \frac{300 m_0 c^2}{e}\left\{\frac{1}{\sqrt{1-(v/c)^2}} - 1\right\};\ 300 m_0 c^2/e = 5.08 \times 10^5 \text{ volt}$$

$$V_v = A \times 10^n;\ V_v^2 = B \times 10^n$$

Unit of V_v = 1 volt.

v/c	V_v		V_v^2		v/c	V_v		V_v^2	
	A	n	B	n		A	n	B	n
0	0	0	0	0	0.30	2.45	4	6.00	8
0.005	6.4	0	4.0	1	0.35	3.43	4	1.18	9
0.006	9.1	0	8.4	1	0.40	4.63	4	2.14	9
0.010	2.54	1	6.4	2	0.45	6.08	4	3.70	9
0.015	5.7	1	3.24	3	0.50	7.86	4	6.18	9
0.020	1.02	2	1.03	4	0.55	1.00	5	1.01	10
0.025	1.58	2	2.51	4	0.60	1.27	5	1.61	10
0.03	2.29	2	5.24	4	0.65	1.60	5	2.56	10
0.04	4.07	2	1.66	5	0.70	2.03	5	4.12	10
0.05	6.36	2	4.04	5	0.75	2.60	5	6.76	10
0.07	1.25	3	1.56	6	0.80	3.39	5	1.15	11
0.10	2.56	3	6.55	6	0.85	4.56	5	2.08	11
0.15	5.82	3	3.39	7	0.90	6.57	5	4.32	11
0.20	1.05	4	1.10	8	0.95	1.12	6	1.46	12
0.25	1.66	4	2.77	8	0.99	3.09	6	9.55	12

TRANSMISSION AND ABSORPTION OF PRIMARY ELECTRONS

During transmission, the beam of primary electrons is more or less scattered. If v_p is great and the film of substance is thin, the scattering may be negligible; it increases with the thickness (τ) and ultimately the electrons emerging from the second surface are distributed as cos φ (66, 84). The thickness at which this first occurs increases with v_p and as the atomic weight decreases; if v_p/c = 0.48 to 0.59 it is 0.015 cm for Al and 0.0002 cm for Au (24).

If primary electrons are incident at all angles, then, for an area which is far from the edges of the surface, $N_{f_2} = e^{-\alpha\tau}$, where α is independent of τ if τ and v_p/c are small (61, 62); if $\theta = 0$, α is independent of τ if $v_p/c < 0.4$ (92); α varies with v_p (*see* Table 2) and the velocity of the electrons decreases as they penetrate the substance (*cf.* Table 4), hence α is independent of τ only if τ is so small that the resulting change in velocity is negligible. To obtain N_{f_2} for a thicker specimen, imagine the specimen to be built up of a series of very thin layers and compute the effect of each of these, taking into account the change of v_p from layer to layer. In this computation, the "most probable velocity" is used. If the initial beam is diffuse (electrons incident in all directions) or if the initial velocity is so low that the beam has become diffuse in a small part of the distance traversed, the velocity may be obtained from Tables 4 and 5. If the incidence is normal and not diffuse, the change in v_p from layer to layer may be obtained by solving the equation $V_{vp}^2 - V_{v\tau}^2 = kd\tau$ (Table 4) for $V_{v\tau}$ and obtaining the corresponding v from Table 1.

For v_p = 0.87c, α/d varies from *ca.* 5 to 14 cm²/g, and for many substances = 7 cm²/g (*cf.* Table 3). Other things being the same, α/d is generally greater for a solid than for a liquid (1).

TABLE 2.—MASS ABSORPTION COEFFICIENT (α/d) AND ITS VARIATION WITH VELOCITY (v_p) OF PRIMARY ELECTRONS (*cf.* TABLE 5)

For A, Br_2, Cl_2, H_2, He, N_2, O_2, CO_2, CH_4, C_2H_4, NH_3 and SO_2, at 0° and 1 A_n and for v_p = 0.35c, $\alpha = 0.0783 MR$ cm^{-1}, where M = molecular weight (14). For many metals, $\alpha/d = a + bZ$ for the β-rays from RaD and RaE (v_p = 0.77c); Z = atomic number, a and b are constants (33, 59). For certain gases, α passes through a maximum at the velocity corresponding to $V_{vp} = V_{m\alpha}$ (*see* 2nd section of this table).

Lenard's data (61, 62) refer to diffuse, and Terrill's (92) to normal, incidence. If α_d [α_n] = value of α for diffuse [for normal] incidence, $\alpha_d = U\alpha_n$; at low velocities, U is practically unity; for values of U at higher velocities, *see* Lenard (61). Unit of α/d = 1 cm²/g; of $V_{m\alpha}$ = 1 volt; $\alpha/d = A \times 10^n$.

(I) Air and Al*

v_p/c	A	n	Lit.	v_p/c	A	n	Lit.
0.00	2.0	7	(61, 62)	0.35	1.4	3	(61, 62)
0.01	1.8	7	(61, 62)	0.36	7.4	2	(92)
0.02	1.3	7	(61, 62)	0.38	6.1	2	(92)
0.03	8.6	6	(61, 62)	0.40	4.9	2	(92)
0.04	5.8	6	(61, 62)	0.40	7.4	2	(61, 62)
0.06	2.5	6	(61, 62)	0.41	4.4	2	(92)
0.08	1.4	6	(61, 62)	0.45	4.0	2	(61, 62)
0.10	8	5	(61, 62)	0.50	2.2	2	(61, 62)
0.15	1.5	5	(61, 62)	0.55	1.3	2	(61, 62)
0.20	3.6	4	(61, 62)	0.60	8.3	1	(61, 62)
0.25	8.6	3	(61, 62)	0.65	4.9	1	(61, 62)
0.27	2.29	3	(92)	0.70	2.9	1	(61, 62)
0.28	1.99	3	(92)	0.75	1.9	1	(61, 62)
0.30	2.9	3	(61, 62)	0.80	1.3	1	(61, 62)
0.32	1.17	3	(92)	0.85	9	0	(61, 62)
0.34	9.2	2	(92)	0.90	6	0	(61, 62)
0.35	8.2	2	(92)				

(II) Velocity of Maximum Absorption

Gas	$V_{m\alpha}$	Lit.	Gas	$V_{m\alpha}$	Lit.
Air	0	(61, 62)	He	4	(18)
A	12	(18)		3.6	(76)
	12.4	(78)	Hg†	0	(17, 71)
	13.2	(76)	Kr	11.3	(76)
CH_4	7.5	(18)	N_2	18	(18)
CO	18	(18)	Ne	22	(76)
Cd†	0	(17, 71)	Xe	6.4	(76)
H_2	0	(18)	Zn†	0	(17)

* For Al, α/d = 7.0 cm²/g if v_p = 0.87c. † Vapor.

TABLE 3.—MASS ABSORPTION COEFFICIENT RELATIVE TO AIR $R = (\alpha/d)/(\alpha/d)_{air}$; for $(\alpha/d)_{air}$, *see* Table 2

Substance	R	v_p/c	Lit.	Substance	R	v_p/c	Lit.
A	0.82	0.35	(14)	I_2	2.36	0.92	(34)
Al	1.00	0.87	(61)	N_2	1.03	0.35	(14)
Br_2	1.56	0.50	(85)	O_2	0.93	0.35	(14)
	1.86	0.92	(34)	Pt	1.94	0.87	(61)
Cl_2	1.23	0.50	(85)	Sn	1.57	0.87	(61)
	1.33	0.92	(34)	CO_2	1.00	0.35	(14)
Cu	1.40	0.87	(61)	CH_4	1.44	0.35	(14)
H_2	1.73	0.35	(14)	C_2H_4	1.22	0.35	(14)
He	0.72	0.35	(14)	NH_3	1.33	0.35	(14)
I_2	1.86	0.50	(85)	SO_2	1.01	0.35	(14)

TABLE 4.—MOST PROBABLE* VELOCITY OF TRANSMITTED ELECTRONS

If v_τ = most probable* velocity of the electrons transmitted by a sheet of thickness τ when the incident electrons have the velocity v_p and are diffuse (incident at all angles) and $\Delta_\tau = v_p - v_\tau$, then Δ_τ/d varies with v_p (*see* Tables 2, 5) and with the transmitting substance. For normal incidence, $V_{vp}^2 - V_{vr}^2 = kd\tau$; if v_p/c = 0.30 to 0.42, $k = 0.40 \times 10^{12}$ volt² cm² g^{-1} for Al, Ag, Au, Be and Cu (91); k decreases from 0.215×10^{12} for Al to 0.105×10^{12} for Au in the order Al, Sn, Cu, Ag, air, Pt, Au (97). The

first [91] appears the more reliable. If $v_p/c = 0.15$ to 0.22, $k = 0.189 \times 10^{12}$ for Al and 0.171×10^{12} for Ni [53].

From the value of Δ_τ for Al (Table 5) the value for the same thickness of another metal M is given by $(\Delta_\tau/d)_M = F_M(\Delta_\tau/d)_{Al}$, $d_{Al} = 2.7$ g/cm³. The following values of F_M [61] are approximate only:

Metal	v/c	F_M	Lit.
Ag	0.9	2.4	[13]
Al	*See* Table 5		
Au	0.1 to 0.3	0.5	[61, 97]
	0.9	3.2	[13]
Cd	0.9	2.4	[13]
Cu	0.6 to 0.7	0.9	[9]
	0.9	1.7	[13]
Fe	0.3 to 0.4	0.5	[61]
Ni	0.9	1.7	[13]
Pb	0.9	3.2	[13]
Pt	0.6 to 0.7	0.7	[9]
	0.9	3.2	[13]
Sn	0.3 to 0.4	0.5	[61]
	0.6 to 0.7	0.8	[9]
	0.9	2.4	[13]
Zn	0.9	1.7	[13]

* If $2(N_2)_v\delta v$ = number of the N_2 electrons which have velocities lying between $v - \delta v$ and $v + \delta v$, then the value of v for which $(N_2)v$ is a maximum is called the "most probable velocity."

TABLE 5.—DECREASE IN NUMBER AND IN MOST PROBABLE* VELOCITY (v) OF ELECTRONS DURING TRANSMISSION THROUGH AL [61, 62]

Recent results [14] for $v_p/c = 0.32$ and 0.41 agree with these older data, *see also* Table 6. Thickness of Al = Af mm; $N_{t2} = i \times 10^n$.

A	$f = 1$			$f = 0.1$		
	v/c	i	n	v/c	i	n
0	0.990	1.00	0	0.800	1.00	0
0.5	0.988	9.17	$\bar{1}$	0.787	8.33	$\bar{1}$
1.0	0.986	8.30	$\bar{1}$	0.773	6.77	$\bar{1}$
1.5	0.984	7.40	$\bar{1}$	0.758	5.40	$\bar{1}$
2.0	0.982	6.50	$\bar{1}$	0.742	4.17	$\bar{1}$
2.5	0.979	5.57	$\bar{1}$	0.723	3.09	$\bar{1}$
3.0	0.974	4.68	$\bar{1}$	0.700	2.13	$\bar{1}$
3.5	0.968	3.80	$\bar{1}$	0.673	1.36	$\bar{1}$
4.0	0.958	2.87	$\bar{1}$	0.640	7.55	$\bar{2}$
4.5	0.946	2.00	$\bar{1}$	0.600	3.19	$\bar{2}$
4.75	0.938	1.57	$\bar{1}$	0.578	1.82	$\bar{2}$
5.00	0.927	1.21	$\bar{1}$	0.551	8.76	$\bar{3}$
5.25	0.911	8.88	$\bar{2}$	0.520	3.09	$\bar{3}$
5.50	0.892	6.04	$\bar{2}$	0.483	6.37	$\bar{4}$
5.75	0.862	3.62	$\bar{2}$	0.437	4.8	$\bar{5}$
6.00	0.820	1.90	$\bar{2}$			
6.25	0.760	8.03	$\bar{3}$			
6.40	0.711	3.0	$\bar{3}$			

* *See* footnote of Table 4.

A	$f = 0.01$			$f = 0.001$		
	v/c	i	n	v/c	i	n
0	0.450	1.00	0	0.300	1.00	0
0.25		7.38	$\bar{1}$		7.87	$\bar{1}$
0.50	0.440	5.33	$\bar{1}$		6.22	$\bar{1}$
0.75		3.57	$\bar{1}$		4.78	$\bar{1}$
1.00	0.429	2.45	$\bar{1}$	0.293	3.64	$\bar{1}$
1.25		1.69	$\bar{1}$		2.74	$\bar{1}$
1.50	0.418	1.09	$\bar{1}$		2.03	$\bar{1}$
1.75		6.65	$\bar{2}$		1.48	$\bar{1}$

TABLE 5.—(*Continued*)

A	$f = 0.01$			$f = 0.001$		
	v/c	i	n	v/c	i	n
2.00	0.406	3.94	$\bar{2}$	0.287	1.03	$\bar{1}$
2.25		2.21	$\bar{2}$		7.34	$\bar{2}$
2.50	0.394	1.24	$\bar{2}$		5.00	$\bar{2}$
2.75		6.35	$\bar{3}$		3.60	$\bar{2}$
3.00	0.380	3.06	$\bar{3}$	0.279	2.26	$\bar{2}$
3.25	0.374	1.38	$\bar{3}$		1.50	$\bar{2}$
3.50	0.364	6.00	$\bar{4}$		9.99	$\bar{3}$
3.75	0.356	1.93	$\bar{4}$		6.52	$\bar{3}$
4.00	0.347	6.42	$\bar{5}$	0.271	4.22	$\bar{3}$
4.25	0.336	1.84	$\bar{5}$		2.56	$\bar{3}$
4.50	0.325	4.23	$\bar{6}$	0.267	1.57	$\bar{3}$
4.75	0.313	7.59	$\bar{7}$		9.75	$\bar{4}$
5.00	0.300	1.27	$\bar{7}$	0.262	6.03	$\bar{4}$
5.25					3.58	$\bar{4}$
5.50				0.257	2.00	$\bar{4}$
5.75					1.10	$\bar{4}$
6.00				0.251	5.85	$\bar{5}$
6.25					3.01	$\bar{5}$
6.40				0.245		

TABLE 6.—VARIATION OF TRANSMISSION WITH PRIMARY VELOCITY: 0.0031 MM AL, NORMAL INCIDENCE [93]

N_{f_2} = number of high velocity electrons ($V_v > 100$ volt), and N_{s_2} = number of low velocity electrons ($V_v < 100$ volt) emerging from second face of Al per unit primary electron striking first face. Total emergent per primary = $N_{f_2} + N_{s_2} = N_t$. Values of v_p/c are computed from V_{vp} (*cf.* Table 1). Unit of $V_{vp} = 1$ kilovolt.

V_{vp}	N_{f2}	N_{s2}	v_p/c	V_{vp}	N_{f2}	N_{s2}	v_p/c
15.0	0.000	0.006	0.24	26.8	0.25	0.14	0.31
18.0	0.000	0.011	0.26	30.2	0.35	0.16	0.33
20.0	0.030	0.020	0.27	32.8	0.42	0.16	0.34
21.2	0.06	0.05	0.28	37.2	0.51	0.17	0.36
22.7	0.11	0.07	0.29	43.4	0.61	0.18	0.39
24.0	0.15	0.10	0.30				

TABLE 7.—DISTRIBUTION OF VELOCITIES AMONG ELECTRONS TRANSMITTED BY AL: NORMAL INCIDENCE [93]

$V_{vp} = 45.6$ kilovolt ($v_p = 0.396c$); τ = thickness of Al; I is proportional to number of transmitted electrons having velocity defined by V_v. Unit of $\tau = 1\mu = 10^{-4}$ cm; of $V_v = 1$ kilovolt = 1000 volt.

V_v	25	29	31	33	35	37	39	41	42	43	44	45
τ	I											
3.1					4.3	9.2	15.6	18.4	19.5	20.0	19.8	14.8
6.2			2.5	3.6	5.4	7.0	7.4	7.0	5.2	4.5	3.7	
9.3	0.8	1.8	2.0	2.3	2.1	1.8	1.4	1.0	0.8	0.6		

REFLECTION OF ELECTRONS: ANGULAR DISTRIBUTION, ETC.

For electron reflection by gases, *see* Baerwald [6]

At β-ray velocities ($v/c = 0.50$ to 0.80), N_{f_1} increases with atomic weight of reflector, but less rapidly than as the first power [65, 67, 80]; unless the thickness (τ) of the reflector exceeds a certain value (τ_m), N_{f_1} increases and the average velocity of the reflected electrons decreases as τ increases [46]. The greater the atomic weight of the reflector, the smaller is τ_m. For $v_p/c =$ 0.48 to 0.59, $(\tau_m)_{Al} = 0.04$ cm, $(\tau_m)_{Pb} = 0.01$ cm [81]; for $v_p/c =$ 0.55 to 0.65, $(\tau_m)_{Al} = 0.013$ cm [68]. For Al with $\tau = 0.032$ cm and $v_p/c = 0.77$, $N_{f_1} = N_{f_2}$ [58]. The angular distribution of N_{f_1} from thick reflectors is shown in Figs. 1, 2, 3 where $n_\theta =$

number of reflected electrons of velocity $\geq v$ which lie within a small cone of solid angle $\Delta\omega$ centered upon the radius vector, n_p = number of incident primary electrons, k = constant of proportionality; $\Delta\omega$ and k are constant for all the curves in any one figure, but they vary from figure to figure. For each curve, the velocity of the incident electrons is indicated by the value of V_{vp} (unit = 1 volt) marked upon the curve; $V_v = 0.90V_{vp}$ unless another value is indicated.

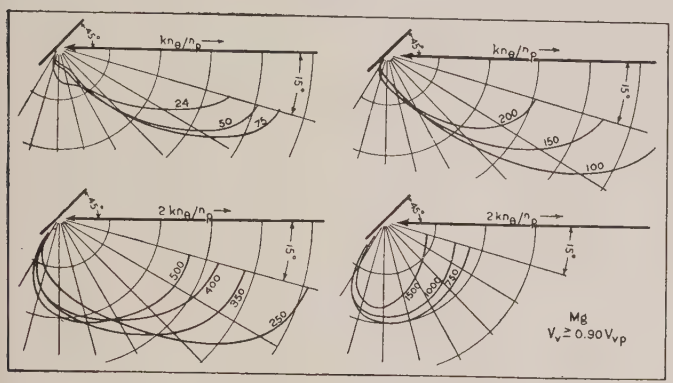

FIG. 1.—Angular distribution of secondary electrons from Mg [23, 24] (*see* text).

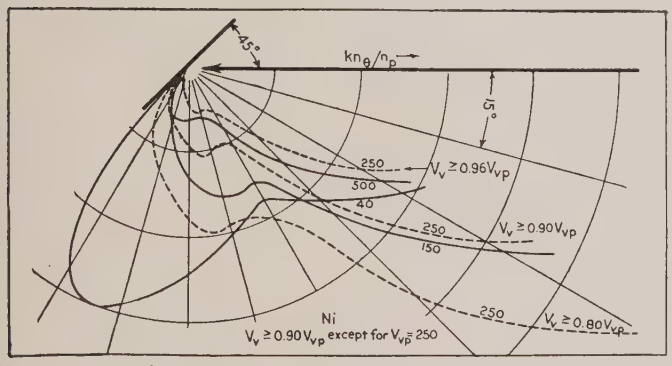

FIG. 2.—Angular distribution of secondary electrons from Ni: variation with the velocity [23, 24] (*see* text).

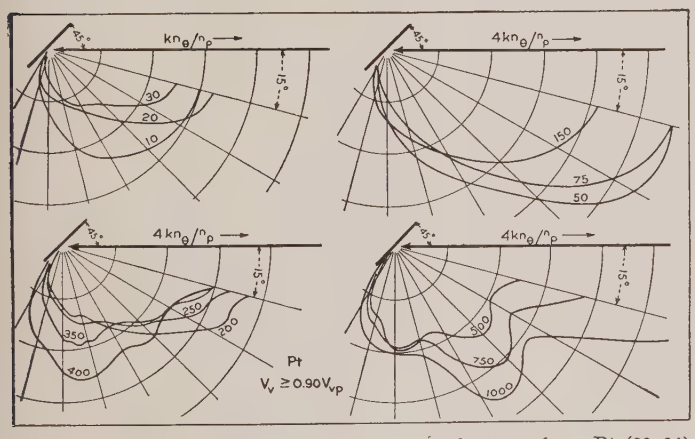

FIG. 3.—Angular distribution of secondary electrons from Pt [23, 24] (*see* text).

TABLE 8.—SECONDARY EMISSION OF ELECTRONS FROM GASES

$n_s = dN_s/dx$ = number of emitted slow electrons per primary and per unit of path; $t_s = \int_0^\infty n_s dx$ = total number of slow electrons per primary at complete absorption. n_s and t_s vary with v_p, and n_s passes through a maximum at $(v_p)_m$ corresponding to $(V_{vp})_m$ (*see* section C of table). If $V_{vp} < 1\,500$ volt, the maximum value of $(V_{vs})_s = 40$ volt and is independent of V_{vp} [94]; if 7 000 volt $\leq V_{vp} \leq 15\,000$ volt, $(V_{vs})_s$ varies from 0 to 1 000 volt, but for 90% of the slow electrons $(V_{vs})_s < 40$ volt [49]. In general, n_s is proportional to d and otherwise is independent of nature of the gas, but H_2 is an exception. For it, n_s/d is greater than for other gases; *see* section B.

A. Air at 0°C and 1 atm. [61]; *see also* Section C

v_p/c	n_s	t_s	v_p/c	n_s	t_s	v_p/c	n_s	t_s
0.006	0		0.25	580	53	0.70	95	1 990
0.024	7 700		0.30	400	100	0.75	80	2 570
0.03	7 500		0.35	308	160	0.80	69	3 310
0.04	5 000		0.40	250	247	0.85	59	4 200
0.05	3 200	(0.5)	0.45	210	385	0.90	50	5 400
0.07	2 300		0.50	180	580	0.95	45	8 600
0.10	1 700	2	0.55	152	830	0.99	41	26 800
0.15	1 200	7	0.60	131	1 150			
0.20	830	20	0.65	111	1 520			

B. H_2, Hydrogen; $(n_s/d)_H = k(n_s/d)_{air}$

v_p/c	0.02	0.062	0.3	0.92
k	12	4	1.8	2

C. Optimum v. Unit of $(V_{vp})_m = 1$ volt; N'_i = fraction of collisions which result in ionization (data of [23] appear to be the best).

Gas	$(V_{vp})_m$	N'	Lit.	Gas	$(V_{vp})_m$	N'	Lit.
Air	130		[69]; *cf.* [16]	N_2.—(*Cont'd*)	100		[51]
					101	0.32	[47]
A	100		[51]		175	0.451	[23]
	80	0.35	[47]	Ne	220		[51]
	125	0.508	[23]		157	0.14	[47]
H_2	125		[69]; *cf.* [16]		330	0.276	[23]
				CO	125		[69]; *cf.* [16]
	74	0.21	[47]				
	145	0.315	[23]		120		[51]
He	140		[51]	CO_2	140		[69]; *cf.* [16]
	147	0.11	[47]				
	200	0.227	[23]	CH_4	132		[69]; *cf.* [16]
Hg	110	0.318	[23]				
N_2	150		[69]; *cf.* [16]		80	0.28	[47]
				HCl	130	0.604	[23]

EMISSION OF SECONDARY ELECTRONS FROM SOLIDS AND LIQUIDS

For angular distribution, *see* Figs. 1, 2, 3; for emission from thin films, *see* Tables 4, 5, 6 and p. 61

Heating in a vacuum increases N_t from Al and Mg and decreases it from other metals. For effect of occluded gases and of surface structure upon N_t from Cu, *see* [31]. With many exceptions, N_t from liquids increases with the atomic weight; it increases with the coefficient of absorption of the primary electrons [1, 2]. Slow secondary electrons do not appear if $V_{vp} < (V_{vp})_s$.

Metal	Ag	Au	Ni	Pd	Pt	W
$(V_{vp})_s$	11	11	9	>9, <12	>9, <12	14 volt [31]

If $v_p/c = 0.55$ to 0.65, $\delta_\theta > 0$ and decreases as atomic weight increases; for Pb, $\delta_{50°} = 0.15$; for the esters, $\delta_{50°} = 2.17$ [2].

v_p/c		0.012	0.018	0.022	0.028	0.040	0.056	0.074
$100\delta_{70°}$	Al [11]	10.7	1.8	25.6	51.1	78.0	123.0	136.0
	Pt [11]	10.8	4.4	33.7	76.5	100.2	127.0	116.0

v_p/c		0.090	0.124	0.198	0.327
$100\delta_{70°}$	Al [11]	144.0	152.0	169.0	173.0
	Pt [11]	106.0	64.9	58.6	45.5

After degassing Pt in high vacuum, $\delta_\theta = 0$ if $4 \leq V_{vp} \leq 500$ volt [95].

$(N_t)\varphi = (N_t)_0 \cos \varphi$ = number emerging at angle φ. For Pt and $V_{vp} \leq 50$ volt, $(N_t)\varphi$ is a maximum when $\varphi = \theta$, if $\theta \leq 60°$ [89]. Early results for greater velocities are unreliable, *see* [66, 84].

If $\theta = 0$ for all primary electrons, N_t varies with V_{vp} as shown in Figs. 4, 5, 6. For Fe, *see* [32]. Earlier results were less reliable and do not agree with these curves, *see* [7, 8, 12, 20, 27, 38, 45, 48, 56, 57].

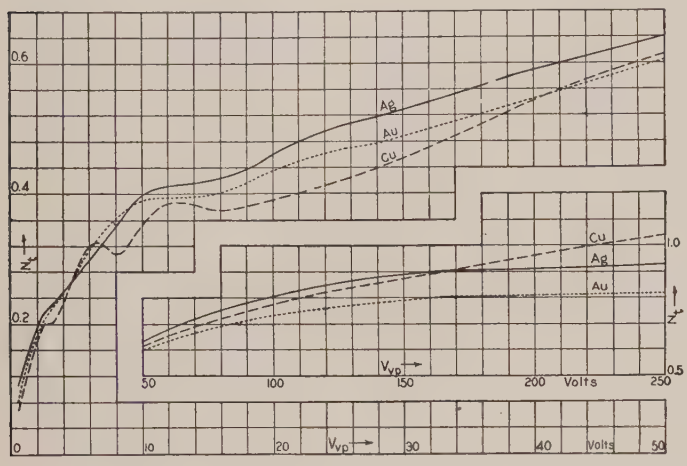

FIG. 4.—Variation in emission (N_t) with the velocity of the primary electrons: Ag, Au, Cu [25].

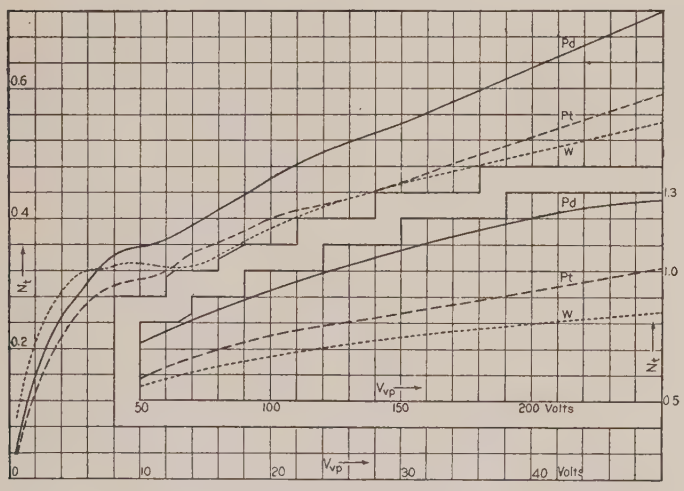

FIG. 5.—Variation in emission (N_t) with the velocity of the primary electrons: Pd, Pt, W [25].

For many metals, N_t is a maximum $(N_t)_m$ at some value of $(V_{vp})_m$ of V_{vp}.

Metal..	Ag, Al, Au	Au	Cu	Cu	Cu, Fe	Fe	Fe	Mo	Ni	W
$(V_{vp})_m$..	200	330	240	750*	200	410†	348	356	455	700 v
$(N_t)_m$...		1.14	1.32				1.3	1.3	1.3	1.45
Lit.....	[88]	[75]	[75]	[64]	[88]	[73]	[74]	[74]	[74]	[75]

* N_t decreases slightly at higher velocities [11].
† At $V = 1500$ volt, N_t is only 0.74 $(N_t)_m$.

VELOCITIES OF SECONDARY ELECTRONS

The lower curves ($V_{vp} > 20$ volt) of Fig. 7 are typical of all metals [31]. If $v_p/c = 0.55$ to 0.65, the average velocity of the secondaries from a pure liquid is greater than that from a pure metal; the velocity increases slightly as the atomic (molecular) weight is reduced [1]. If $v_p/c = 0.9$ (*ca.* $V_{vp} = 660$ kilovolt), the velocities of the secondaries are distributed over a large range, but the average corresponds to *ca.* 1 kilovolt. For blackened metal surfaces, *see* [15].

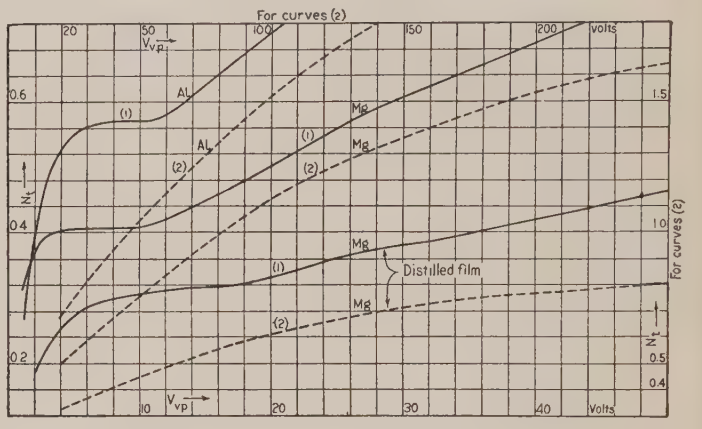

FIG. 6.—Variation in emission (N_t) with the velocity of the primary electrons: Al, Mg [25].

Curves (1) are referred to scales at left and below; curves (2) to scales at top and right. The two lower curves refer to Mg which has been distilled upon the target.

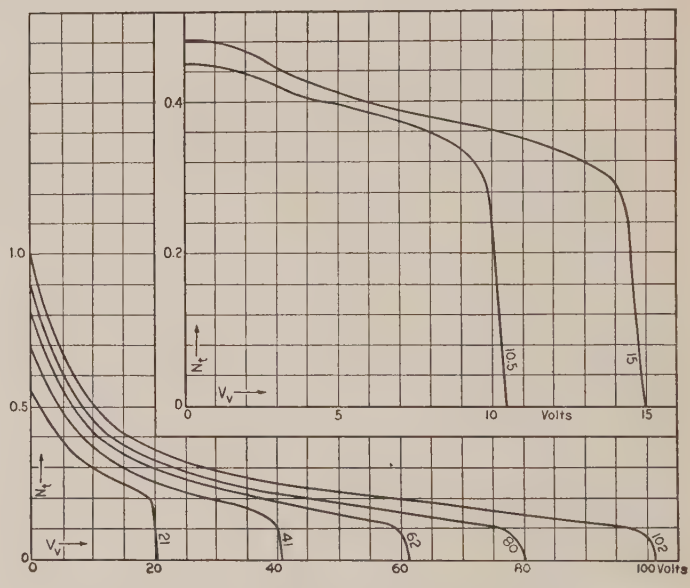

FIG. 7.—Velocities of secondary electrons [25].

Ordinates indicate the number (N) of secondary electrons, per primary, which have velocities greater than that indicated by the corresponding abscissae (V_v). Each curve intersects the axis of abscissae at the point V_{vp} which defines the velocity of the primary electrons to which the curve refers.

TABLE 9.—ELECTRON EMISSION EXCITED BY IMPACT OF SLOWLY MOVING POSITIVE IONS

For emission from α-ray impact, *see* Vol. I, p. 365; for absorption of positive ions, *see* [99]

Even if V_{vp} = several hundred volts, the velocity of the emitted electrons is low, $V_v = 0$ to 30 volt [3, 4, 36, 37]; for those emitted from second side of thin film of Au, $V_v < 40$ if $V_{vp} \leq 21\,750$ volt, and for 75% of them $V_v < 1.25$ if $V_{vp} = 6\,350$ volt [40].

As V_{vp} is reduced, the number (N^-) of emitted electrons approaches 0, asymptotically in the case of solids and more abruptly in the case of gases; $N = 0$ if $V_{vp} < (V_{vp})_0$; data for

$(V_{vp})_0$ are discordant. Preheating reduces N^-. Before heating, $(V_{vp})_0$ = 20 to 30 volt for all solids ([3], [4]), = 20 volt for Pt ([44]). After heating, as follows; unit of V = 1 volt:

Metal	$(V_{vp})_0$	N_{1-}*	N_{1+}*	V_{v1-}	ions†	Lit.
Al	200	0.07	0	<1	K	[50]
Ni	300	0.042	<0.02	<1	K	[50]
Ni	50‡	‡	‡		$AlPO_4$	[52]
Mo	600	0.038	<0.02	<1	K	[50]

* Values for V_{vp} = 1000.

† Source of ions bombarding target.

‡ After heating Ni to 1000°C; $N_{1-} = 1.5(V_{vp})^2(10)^{-6}$ if $V_{vp} \leq 380$; N_{1+} is great; v_{1+} is small. Data appear to be less reliable than those of [50].

For gases the following values of $(V_{vp})_0$ are recorded; unit = 1 volt: Impact of +Na on Hg vapor [90], ≤40, air [10] <6, +H on H_2 gas [42] >925 [earlier and much lower values (≤18 [79], <6 [10]) are attributed to emission from walls of chamber], He [44] >200, for any gas $(V_{vp})_0$ is of same order as for electronic impact [72]. For values of $(V_{vp})_0$ for electronic impact, *see* p. 69.

For gases, $n(=dN/dx)$ increases with the velocity and is proportional to the pressure, temperature being constant. For impact of +H ions on H_2 at 1 atm. and room (?) temperature:

V_{vp}	5	18	25	31	Unit = 1 kilovolt
n [4, 5]	76	152	228	260	Unit = 10^6

For solids, N_1 increases with the velocity and with the angle of incidence; for thin films, N_1 is independent of thickness [40]. For Au foil, thickness not stated, unit of V_{vp} = 1 kilovolt:

V_{vp}	5	10	15	20	25
N_2	0	0.1	1.0	3.0	6.0

The number of + ions emitted is *ca.* $N_2/3$; for double thickness, divide N_2 by 10 [40]. For insulators, N is less than for metals [54]. The law of absorption of H canal rays in thin metal foil is similar to that for α-rays [43] (*see* Vol. I, p. 368). Unit of V_{vp} = 1 volt. Metals not gas-free. Signs −[+] indicate electrons [positive ions].

V_{vp}	N_{1-}	N_{1+}	V_{vp}	N_{1-}	N_{1+}
Target = Cu + ions = Na and Al* [21]			Target = Brass [3, 4] + ions = H		
400	0.049		300	2.0	
2 000		0.07	5 000	3.45	
8 000	1.5		18 000	4.8	
38 000	2.8	0.10	25 000	5.4	
48 000	1.4		31 000	5.4	
+ ions = H [35]					
15 000	0.89	0.083			
31 000	1.36	0.15			

V_{vp}	1 000 N_{1-}			V_{vp}	1 000 N_{1-}		
	K	Li	Rb		K	Li	Rb
Target = Pt [22]				Target = Al [22]			
74		6		74	4		
115			1.6	125	8		
146	4.5	13	2	146	11		
190	7	17	3	177		10	
235			5	215	18	20	
250	12.5			275	25	58	8
265		19		340	37	93	14
275	14	7		375	47		
300	24			450	67	138	22
350	17		8	475	80		
360		26		535		214	36
390		30		560	92		
400	19.5		9				
475	20.7	36					
560	25	43	12				

* Ions from heated phosphates of Na and Al.

LITERATURE

(For a key to the periodicals see end of volume)

[1] Allen, *2*, **29**: 177; 09. [2] Allen, *2*, **30**: 276; 10. [3] Baerwald, *8*, **41**: 643; 13. **42**: 1287; 13. **60**: 1; 19. [4] Baerwald, *8*, **65**: 167; 21. [5] Baerwald, *88*, **14**: 867; 12. **16**: 789; 14. [6] Baerwald, *8*, **76**: 829; 25. [7] v. Baeyer, *88*, **10**: 96; 08. [8] v. Baeyer, *88*, **10**: 953; 08. *63*, **10**: 176; 09. [9] v. Baeyer, *63*, **13**: 485; 12. *200*, **11**: 66; 14.

[10] v. Bahr and Franck, *88*, **16**: 57; 14. [11] Baltruschat and Stark, *63*, **23**: 403; 22. [12] Barber, *2*, **17**: 322; 21. [13] Baxman, *Diss.* Halle, 1911. [14] Becker, *8*, **17**: 381; 05. *171*, **19A**, 16; 10. *8*, **75**: 435; 24. **78**: 209; 25. [15] Becker, *8*, **78**: 228, 253; 25. [16] Block, *8*, **38**: 559; 12. [17] Brode, *5*, **109**: 397; 25. [18] Brode, *2*, **25**: 636; 25. [19] Campbell, *8*, **17**: 180; 09.

[20] Campbell, *8*, **22**: 276; 11. **24**: 527; 12. **25**: 803; 13. **28**: 286; 14. **29**: 369; 15. [21] Campbell, *8*, **29**: 783; 15. [22] Cheney, *2*, **10**: 335; 17. [23] Compton and Van Voorhis, *2*, **27**: 724; 26. [24] Crowther, *5*, **80**: 186; 08. [25] Crowther, *Ions, electrons and ionizing radiations.* New York, Longmans, 1924. [26] Crowther and Schonland, *5*, **100**: 526; 22. [27] Dadourian, *2*, **14**: 434; 19. [28] Danysz, *6*, **30**: 241; 13. [29] Davisson and Kunsman, *2*, **22**: 242; 23.

[30] Davisson and Kunsman, Bell Telephone Labs., New York City, *0.* [31] Farnsworth, *2*, **20**: 358; 22. **21**: 204; 23. **25**: 41; 25. [32] Farnsworth, *2*, **27**: 413; 26. [33] Fournier, *34*, **180**: 284, 1490; 25. [34] Friman, *8*, **49**: 373; 16. [35] Fuchtbauer, *63*, **7**: 153; 06. [36] Fuchtbauer, *63*, **7**: 748; 06. [37] Fuchtbauer, *8*, **23**: 301; 07. [38] Gehrts, *8*, **36**: 995; 11. [39] Geiger and Bothe, *63*, **22**: 585; 21. *96*, **6**: 204; 21.

[40] Hahn, *96*, **14**: 355; 23. [41] Hartig, *2*, **25**: 111; 25. [42] Hooper, *143*, **201**: 311; 26. [43] Homma, *8*, **80**: 609; 26. [44] Horton and Davies, *5*, **95**: 333; 19. [45] Horton and Davies, *5*, **97**: 23; 20. [46] Huff, *2*, **35**: 194; 12. [47] Hughes and Klein, *2*, **23**: 450; 24. [48] Hull, *2*, **7**: 1; 16. [49] Ishino, *8*, **32**: 202; 16.

[50] Jackson, *2*, **28**: 524; 26. [51] Jesse, *2*, **26**: 208; 25. [52] Klein, *2*, **26**: 800; 25. [53] Klemperer, *96*, **34**: 532; 25. *63*, **26**: 751; 25. [54] Koenigsberger and Gallus, *88*, **16**: 190; 14. [55] Kossel, *8*, **37**: 393; 12. [56] Kovarik, *3*, **20**: 849; 10. [57] Kovarik and McKeehan, *63*, **15**: 434; 14. [58] Kovarik and McKeehan, *2*, **6**: 426; 15. [59] Lattes and Fournier, *34*, **181**: 855; 25.

[60] Laub, *8*, **23**: 285; 07. [61] Lenard, *Quantitatives über Kathodenstrahlen aller Geschwindigkeiten.* Heidelberg, Winther, 1925. [62] Lenard, *8*, **56**: 255; 95. **12**: 714; 03. [63] Leithäuser, *Diss.*, Berlin, 1903. *8*, **15**: 283; 04. [64] McAllister, *2*, **19**: 246; 22. **21**: 122; 23. [65] McClelland, *434*, **9**: 9; 06. [66] McClelland, *5*, **80**: 501; 08. [67] McClelland and Hackett, *434*, **9**: 27; 06. [68] Madsen, *3*, **18**: 909; 09. [69] Mayer, *171*, **15A**: 13; 13. *8*, **45**: 1; 14.

[70] Mayer, *8*, **64**: 451; 21. [71] Minkowski, *96*, **18**: 258; 23. [72] Pawlow, *5*, **90**: 398; 14. [73] Petry, *2*, **25**: 583; 25. [74] Petry, *2*, **26**: 346; 25. [75] Petry, *2*, **28**: 362; 26. [76] Ramsauer, *8*, **64**: 513; 21. **66**: 546; 22. **72**: 345; 23. [77] Robinson, *8*, **31**: 769; 10. [78] Rusch, *63*, **26**: 748; 25. *8*, **80**: 707; 26. [79] Saxton, *3*, **44**: 809; 22.

[80] Schmidt, *200*, **5**: 451; 08. [81] Schmidt, *8*, **23**: 671; 07. [82] Schmidt, *63*, **10**: 929; 09. [83] Schonland, *5*, **101**: 299; 22. **108**: 187; 25. [84] Seitz, *8*, **6**: 1; 01. [85] Silbermann, *Diss.*, Heidelberg, 1912. [86] Stark, *Kathodenstrahlen*, in *Handb. Radiologie*, **V**; 1919. [87] Stuhlman, *166*, **56**: 344; 22. [88] Stuhlman, Univ. North Carolina, *0.* [89] Tate, *2*, **17**: 394; 21.

[90] Tate, *2*, **23**: 293; 24. [91] Terrill, *2*, **22**: 101; 23. [92] Terrill, *2*, **24**: 616; 24. [93] Terrill, Columbia University, New York City, *0.* [94] Thomson, *201*, **14**: 541; 08. [95] Tingwaldt, *96*, **34**: 280; 25. [96] Traubenberg and Hahn, *96*, **9**: 356; 22. [97] Whiddington, *5*, **86**: 360; 12. **89**: 554; 14. [98] Wilson, *5*, **84**: 141; 10. [99] Wien, *8*, **48**: 1089; 15.

[100] Wilson, *5*, **85**: 240; 11.

PHOTOCONDUCTIVITY AND PHOTO-ELECTROMOTIVE FORCE

A. Ll. Hughes

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Photoconductivity.—If, apart from temperature change, an illumination of a substance alters its resistivity, the substance is said to exhibit photoconductivity. So far as known, the alteration is always a decrease in the resistivity. The effect varies with the wave-length of the light and that wave-length (λ_m) at which the effect is a maximum is the most important and definite characteristic of the substance with reference to its photoconductive properties. The amount the resistivity of a substance is decreased by a given illumination varies greatly from specimen to specimen, being profoundly modified by small amounts of impurities.

Photo-emf.—If argentite (Ag_2S) is provided with two similar metallic electrodes, the illumination of one of the contacts causes it to acquire a positive potential with reference to the other. The most effective illumination is λ = *ca.* 10 000 Å; with increasing intensity of illumination, the emf reaches a limiting value (0.013 volt) at 600 meter-candle [13]. If two electrodes of the same metal are immersed in an electrolyte and one of them is illuminated, it acquires a potential which differs from that of the unilluminated electrode. For Cu, Hg, and Pt, the illuminated electrode is the more positive; for Ag and Au, the opposite is true. The nature of the electrolyte is unimportant [1].

Table 1.—Minerals Exhibiting Photoconductivity [2]

Out of 175 substances examined with light from an electric arc, the following 19 exhibited photoconductivity. The magnitudes of the effect are indicated roughly by the symbols: s = small, m = medium, g = great, vg = very great.

Ag_3AsS_3	Proustite	g
Ag_9AsS_6	Pearceite	m
AgI	Iodyrite	m
Ag_2O	Silver oxide	m
Ag_2S	Acanthite	g
Ag_2S	Argentite	g
$AgSbS_2$	Miargyrite	m
Ag_3SbS_3	Pyrargyrite	m
Ag_5SbS_4	Stephanite	m
Ag_9SbS_6	Polybasite	m
Bi_2S_3	Bismuthinite	vg
Cu_2O	Cuprite	m
$(Cu_2, Pb)_3Sb_2S_6$	Bournonite	g
MoS_2	Molybdenite	m
PbS	Galena	m
$Pb_2Sb_2S_5$	Jamesonite	m
$Pb_3Sb_2S_6$	Boulangerite*	g
Sb_2S_3	Stibnite	s
Se	Selenium	m

* Embrithite.

Table 2.—Solutions Exhibiting Photoconductivity [14]

Solvent is *n*-hexane (C_6H_{14})

Formula	Substance	Formula	Substance
$C_{10}H_6O_4$...	Naphthazarine	$C_{14}H_{10}$...	Anthracene*
$C_{10}H_8O$...	α-Naphthol	$C_{14}H_{10}$	Phenanthrene
$C_{10}H_8O$...	β-Naphthol	$C_{14}H_{12}$...	Stilbene
$C_{10}H_9N$...	α-Naphthylamine	$C_{15}H_{12}$...	Methylanthracene
$C_{14}H_8O_4$	Quinizarin	$C_{18}H_{12}$	Chrysene

* Conductivity increased 1 000 times by illumination with light of λ = 2 250.

Table 3.—Wave-length (λ_m) for Maximum Photoconductivity

Unit of λ_m = 1 Å = 10^{-8} cm; t = °C; t_r = room temperature

Formula	Substance	λ_m	t	λ_m	t	Lit.
AgBr		4 600	t_r			(7)
AgCl		3 800	t_r			(7)
AgI		4 700	t_r	5 000	t_r	(7)
Ag_2S	Acanthite	13 500	22	4 100	t_r	(4)
		12 000	−153			(4)
Ag_2S	Argentite	13 500	22	4 100	t_r	(4)
		11 100	−153	11 200	−110	(4)
Ag_3SbS_3	Pyrargyrite	6 300	15	6 300*	−180	(6)
Bi_2S_3	Bismuthinite	10 800	−166	6 400	−166	(9)
Cu_2O	Cuprous oxide	2 800†	t_r	6 250	t_r	(12)
$(Cu_2, Pb)_3Sb_2S_6$	Bournonite	9 500‡	t_r	5 500‡	t_r	(6)
I	Iodine	5 400	t_r			(5)
MoS_2	Molybdenite	18 000	15	10 200§	15	(8)
		8 500	15	7 000‖	15	(8)
		8 500‖	−180			(8)
PbI_2		5 200¶	t_r	4 500¶	t_r	(7)
Sb_2S_3	Stibnite	7 500	15	6 800	−180	(11)
Se	Selenium	7 000	t_r	5 500	t_r	(10)
		7 000	15	6 000	−180	(11)
TlBr		4 130**	t_r			(7)
TlCl		3 650**	t_r			(7)
TlI		4 130**	t_r			(7)
	Thalofide††	10 000	t_r			(3)

* Maximum sharper than at higher temperature.
† Principal maximum.
‡ Maximum is ill-defined.
§ Strongest at this temperature.
‖ Weak at this temperature.
¶ Sharp maximum.
** Width of peak *ca.* 800 Å.
†† Thallium oxysulfide; sensitivity ranges from λ = 4 000 to λ = 12 000, where it ends abruptly.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Audubert, *34*, **177**: 818; 23. (2) Case, *2*, **9**: 305; 17. (3) Coblentz, *31A*, **16**: 253; 20. (4) Coblentz, *31A*, **18**: 265; 22. (5) Coblentz, *31A*, **18**: 585; 22. (6) Coblentz and Eckford, *31A*, **18**: 353; 22. (7) Coblentz and Eckford, *31A*, **18**: 489; 22. (8) Coblentz and Kahler, *31A*, **15**: 121; 20. (9) Coblentz and Kahler, *31A*, **15**: 231; 20.
(10) Dieterich, *2*, **8**: 191; 16. (11) Elliott, *2*, **5**: 53; 15. (12) Pfund, *2*, **7**: 289; 16. (13) Geiger, *2*, **22**: 461; 23. (14) Volmer, *99*, **16**: 186; 17.

PHOTOEMISSION OF ELECTRONS

A. Ll. Hughes

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When a substance is illuminated by light of a sufficiently high frequency it emits electrons; this is the photoelectric effect. The photoelectric threshold (λ_0) is the longest wave-length capable of producing the effect. For solids and liquids, λ_0 depends upon surface conditions; observed values vary widely ([8, 26, 42, 47, 53, 61, 64, 65]). The strength of the photoelectric current from an illuminated surface is proportional to the intensity of the incident light ([6, 7, 12, 27, 28, 31, 50]) and varies with the wave-length, frequently passing through a maximum at a certain wave-length (λ_m) characteristic of the substance. A substance may have a λ_m without exhibiting a "selective" photoelectric effect, as presently defined. The current varies with the age of the surface ([35]) (*see* Fig. 1), and depends upon the gas content; the evidence regarding its possible variation with the temperature is somewhat conflicting; for Al in range 20 to −180°C ([37, 38]), Ag, Au, Fe 15 to 125°C ([36]), K 20 to 110°C ([4]), Mg 15 to 125°C ([36]), Na 20 to 110°C ([4]) and 20 to −180°C ([2]), NaK alloy 20 to 110°C ([4]), Ni, Pb 15 to 125°C ([36]), Pt 60 to 300°C ([62]), and Sb, Zn 15 to 125°C ([36]) no variation was observed, but Ives ([20]) found that the current from K and from Na decreased as the temperature was reduced from 0 to −180°C, the reduction being 20 % for blue and 45 % for yellow light; the lower the temperature, the more rapid was the variation. For all these observations the metals were in a vacuum.

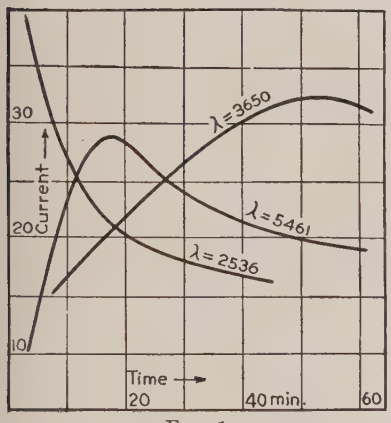

FIG. 1.

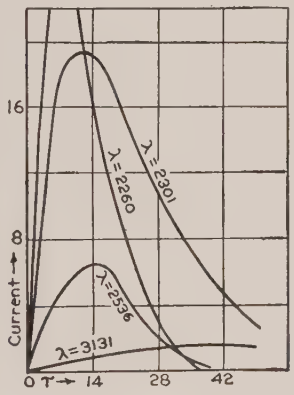

FIG. 2.

FIG. 1.—Variation of photoelectric current with age of surface ([35]).

Na shaved *in vacuo;* age measured from time of shaving; current expressed in arbitrary units; unit of $\lambda = 1$ Å $= 10^{-8}$ cm.

FIG. 2. Variation of photoelectric current with thickness (τ) of film ([59]).

Pt deposited *in vacuo* by evaporation from wire to a quartz (SiO_2) plate; current, expressed in arbitrary units, per unit energy of radiation; unit of $\tau = 1$ mμ $= 10^{-7}$ cm, of $\lambda = 1$ Å $= 10^{-8}$ cm.

With the alkali metals, measurable currents have been obtained ([7]) with an energy flow of 3×10^{-9} erg/cm² sec of blue, and of 2×10^{-7} erg/cm² sec of orange, light. The greatest charge liberated per calorie of incident radiation is of the order of 0.01 coulomb; for Pt λ 2000 the charge liberated is 3.0×10^{-5} coulomb/calorie, for Al λ2200 it is 22.5×10^{-5}, for Na λ3700 it is 171×10^{-5} and for Na λ2300 it is 330×10^{-5}, same unit for all ([49]); *see also* ([56]).

If the light is plane polarized and is incident obliquely upon the surface, the photoelectric current from some substances and at a certain wave-length (λ_s) is much greater when the electric vector E lies in the plane of incidence than when it is perpendicular to it. Such a substance is said to exhibit a "selective" effect at λ_s; in unpolarized light λ_m coincides with λ_s. Very few metals having a λ_m have also a λ_s ([21]). The alkali metals exhibit a selective effect only when in thin films and of the alloys, only NaK_x exhibits it ([21]).

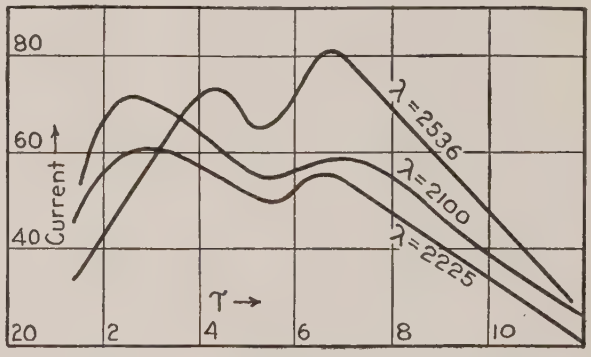

FIG. 3.—Variation of photoelectric current with thickness (τ) of film ([3]).

Pt deposited by cathode sputtering; current expressed in arbitary units; unit of $\tau = 1$ mμ $= 10^{-7}$ cm, of $\lambda = 1$ Å $= 10^{-8}$ cm.

Evidence derived from thin films ([19, 41, 43]) now favors the view that, at instant of liberation, photoelectrons are emitted in all directions in equal numbers and with equal velocities. For variation of photoelectric current with thickness of film, *see* Figs. 2, 3.

TABLE 1.—PHOTOELECTRIC THRESHOLDS

a[*b*] = surface mechanically cleaned before [after] being placed in vacuum; *c* = distilled in vacuum; *d* = data for tiny drops; *e* = special care taken to outgas the substance in vacuum; *f* = surface newly formed in vacuum; *g* = data for gas phase. Unit of $\lambda_0 = 1$ Å $= 10^{-8}$ cm.

TABLE 1.—(*Continued*)

Element	λ_0	Lit.	Element	λ_0	Lit.
Ag	3390*a*	(13)	K§.—(*Cont'd*)	>6000	(67)
	3250	(60)		<7000	(67)
Al	4770*a*	(48)	Li	5800*b*	(34)
	3342*a*	(14)	Mg**	3820*a*	(48)
	3595*a*	(13)	Na	5830*a*	(48)
As	2360*c*	(17)		6800*b*	(34)
Au	*		Ni	3050*a*	(13)
Bi	3300*a*	(48)	Pb	3115*c*	(17)
	3225*c*	(17)		2980*a*	(13)
	2980*a*	(13)	Pt††	2800*a*	(48)
C†	2615*a*	(13)		2780*a*	(13)
Ca	3700*c*	(17)		2840	(60)
	4000*a*	(13)		2570*e*	(24)
Cd	3140*c*	(17)	S	<3300	(10)
	3130*a*	(13)		<2400*d*	(23)
Cl	<1250*g*	(33)		>2200*d*	(23)
Cs	3180g‖	(29)	Se	2200*c*	(17)
Cu	3000*a*	(48)		2670*a*	(13)
	3050*a*	(14)	Sn	3620*a*	(48)
	2665*a*	(13)		3050*a*	(14)
Fe, *cf.* (2.5)	3050*a*	(14)		3185*a*	(13)
	2870*a*	(13)	Th	3465*a*	(13)
Hg	>1800*g*‡	(58)	W	2615*a*	(13)
	2735*f*	(22)		2300*e*	(11)
Ir	*		Zn‡‡	3760*a*	(48)
K§	>2800*g*‖	(66)		3200*a*	(14)
	<3100*g*‖	(66)		3016*c*	(17)
	4360¶	(47)		3425*a*	(13)

Formula	Substance		λ_0	Lit.
	Air		*ca.* 1300	(15,40)
CuO			2500	(34)
$SnCl_4$	Tin tetrachloride	*g*	<1800	(16)
$Zn(C_2H_5)_2$	Zinc ethyl	*g*	<1800	(16)
CS_2	Carbon disulfide	*g*	<1800	(16)
C_6H_7N	Aniline	*g*	>1850	(54)
$C_{10}H_9N$	α-Napthylamine	*g*	>1850	(57)
$C_{12}H_{11}N$	Diphenylamine	*g*	>1850	(57)
$C_{13}H_{12}$	Diphenylmethane	*g*	>1850	(57)
$C_{14}H_{10}$	Anthracene	*g*	>1850	(57)
	Anthracene		2170	(18)
	Anthracene		2250	(63)
	Anthracene in hexane		2250	(63)
	Oil (watch-oil)		<2150	(23)
	Paraffin		<2150	(23)
	Shellac		<2200	(23)
BaO	(At 420°C, λ_0 = 3880) 20°C.		2860	(24)
$CaHg_x$	Ca amalgam		3500§§	(46)
SrO	(At 420°C, λ_0 = 3880) 20°C.		2860	(24)

* λ_0 is not given, but observations (30) indicate that it is independent of temperature between 20 and 860°C.

† For soot (lampblack) λ_0 independent of temperature between 0 and −180°C (32).

‡ Does not agree with value expected from ionizing potentials.

§ Ives (20) found λ_0 shifted from 7000 to 6200 as *t* changed from 20 to −180°C.

** For newly distilled Mg, λ_0 shifted from 3500 to 5500 in 24 hr, in high vacuum (46).

‖ Agrees with value expected from ionizing potential.

¶ After repeated distillations in very high vacuum $\lambda_0 < 3300$ (65), others under equally good and similar conditions find $\lambda_0 = 4360$ (47).

†† After heating to 900°C for 8 hr, $\lambda_0 = 2700$; after heating to 1400°C and outgassing, $\lambda_0 < 1850$ (61). λ_0 is independent of temperature (24), at least for range 20 to 860°C (30). For Pt-black, λ_0 independent of temperature for range 0 to −180°C (32).

‡‡ For new surfaces prepared in highest obtainable vacuum $\lambda_0 < 1850$ (26).

§§ Shifts to 6000 in course of a few hr; observed in high vacuum (46).

TABLE 2.—WAVE-LENGTH (λ_m) FOR MAXIMUM PHOTOELECTRIC SENSITIVITY

B = breadth = spectral range over which the photoelectric effect is unusually great. For example: For K, λ_m = 4400, *B* = 2500; that is, the effect is unusually great from *ca.* λ = 3150 to 5650. The substance was in a vacuum (*v*) or in argon (A). Unit of λ_m and of *B* = 1 Å = 10^{-8} cm.

Substance	Gas	λ_m	*B*	Lit.	Substance	Gas	λ_m	*B*	Lit.
Ba	*v*	2800		(44)	KTl_x	*v*	3000	3200	(44)
Cs	*v*	4800		(21)	Li	*v*	2800		(44)
	A	5390		(52)		A	4050		(52)
CsH	A	5400		(52)	Na	A	4190		(52)
CsK_x	*v*	4800		(21)		A	4400		(55)
$CsNa_x$	*v*	4800		(21)		*v*	3400	3200	(44)
$CsRb_x$	*v*	4800		(21)	NaH	A	4270		(52)
K	A	4400		(52,		A	4400		(55)
				(55)	$NaRb_x$	*v*	4500		(21)
	v	4400	2500	(44)	Rb	A	4700		(52)
	v	4400	2100	(9)		A	4560		(55)
	v	4000		(21)		*v*	4700	1800	(44)
KH	A	4560		(52)		*v*	4800		(9)
	A	4400		(55)		*v*	4500		(21)
KHg_x	*v*	3800	2900	(44)	RbH	A	4810		(52)
KNa_x	*v*	3900	2900	(44)		A	4560		(55)
KRb_x	*v*	4500		(21)					

TABLE 3.—ILLUSTRATING VARIATION OF PHOTOELECTRIC SENSITIVITY WITH WAVE-LENGTH (λ) OF INCIDENT LIGHT

For each metal the unit is chosen so as to make the sensitivity 100 for a certain wave-length. When light is not monochromatic, λ_{min} = approximately the shortest λ in the light used. Unit of λ = 1 Å = 10^{-8} cm (45).

λ	Bi	Cd	Pb	Sn	Tl
2300	100	100	100	100	100
2540	56.3	59.2	50.4	55.2	62.1
3130	<1	<1	1.6	1.4	5.8
3650	0	0	<1	<1	<1

Light source is Al spark, filtered (39)

Filter	λ_{min}	CuO	Ice	Water
CaF_2, Fluorite*	1250	100	100	100
SiO_2, Quartz	1450	27	40	15
SiO_2 + Air	1770	22	50	11
$CaCO_3$, Calcite	2200	<1	0.02	0
Glass	3300	0	0	0

* Relative values are: CuO = 100, Ice = 70, Water = 0.25.

TABLE 4.—RELATIVE VALUES OF PHOTOELECTRIC CURRENT (*I*) FOR HETEROCHROMATIC ILLUMINATION

The data given in different sections of the table are not comparable, as the relative intensities and spectral distributions are not known. Unit of *I* is arbitrary and varies from section to section.

Symbol	*I*	Symbol	*I*	Symbol	*I*
		Hg-arc (5)			
Bi_2O_3	110	$FeCl_2$	26	HgCl	12
Bi_2O_5	70	$FeCl_3$	1	$HgCl_2$	2
Cr_2O_3	50	FeO	7 200	HgI	112
CrO_3	1	Fe_2O_3	202	HgI_2	10
CuCl	50 000	$Hg(C_6H_5-$		Hg_2O	280
$CuCl_2$	10	$CO_2)$	18	HgO	70
Cu_2O	14 400	$Hg(C_6H_5-$		MnO	500
CuO	4 800	$CO_2)_2$	12	Mn_3O_4	130

TABLE 4.—(*Continued*)

Symbol	*I*	Symbol	*I*	Symbol	*I*
Hg-arc (5)		Hg-arc (5)		Zn-spark (51)	
MnO_2	48	KBr	320	MnS_2	141
PbO	3 200	KCl	67	MoS	28
PbO_2	1 700	KI	1 200	NiS	102
SnO	1. 220	$PbBr_2$	97	PbS	887
SnO_2	24	$PbCl_2$	31	Sb_2S_5	45
SnS	1 400	PbI_2	3 000	SnS	236
SnS_2	186	Zn-spark (51)		Zn	530*
AgBr	430	Ag_2S	240	ZnS	80
AgCl	200	Al	200*	Hg-lamp (1)	
AgI	750	Bi_2S_3	138	Ag_2S	2 150
$CdBr_2$	21	CdS	58	Bi_2S_3	112
$CdCl_2$	60	CoAsS	89	CdO	27
CdI_2	18	CoS	29	CoS	820
HgBr	19	Cr_2S_3	160	CuO	295
$HgBr_2$	14	Cu_2S	534	CuS	490
HgCl	15	CuS	391	FeS	91
$HgCl_2$	5	FeS	64	PbO_2	15
HgI	1 400	FeS_2	176	PbS	1 070
HgI_2	230	Fe_7S_8	122	SnS	346
		MnS	385		

* Assumed as a basis of reference.

TABLE 5.—RELATIVE PHOTOELECTRIC SENSITIVITIES OF AQUEOUS SOLUTIONS AND ALLOYS: VARIATION WITH CONCENTRATION (39)

Of the Pd-Ag alloys saturated with H, that of 40% Ag has maximum sensitivity and also maximum absorptive power for H (25). Nature of light source is unknown. Unit is so chosen that sensitivity of pure $H_2O = 1$. Unit of concentration = 1%.

Concn.	NaCl	Na_2SO_4	$NaNO_3$	Na_2CO_3	KCl	K_2SO_4
2	0.85	3.25			0.35	1.56
10	0.50	4.65	4.11	3.97	0.30	3.60
15	0.50	5.60			0.30	5.40

LITERATURE

(For a key to the periodicals see end of volume)

(1) Aulenkamp, *96*, **18**: 70; 23. (2) Burt, *2*, **23**: 774; 24. (2.5) Cardwell, *197*, **14**: 439; 28. (3) Compton and Ross, *2*, **13**: 374; 19. (4) Dember, *8*, **23**: 957; 07. (5) Dima, *34*, **156**: 1366; 13. **157**: 590; 13. (6) Elster and Geitel, *8*, **48**: 625; 93. *63*, **14**: 741; 13. (7) Elster and Geitel, *63*, **17**: 268; 16. (8) Elster and Geitel, *63*, **21**: 361; 20. (9) Farwig, *96*, **21**: 38; 24.

(10) Goldmann and Kalandyk, *8*, **36**: 589; 11. (11) Hagenow, *2*, **13**: 415; 19. (12) von Halban and Ebert, *96*, **14**: 182; 23. (13) Hamer, *48*, **9**: 251; 24. (14) Hennings, *2*, **4**: 228; 14. (15) Hughes, *201*, **15**: 483; 10. (16) Hughes, *201*, **16**: 376; 11. (17) Hughes, *62*, **312**: 205; 12. (18) Hughes, *3*, **24**: 380; 12. (19) Hughes, *337*, **2**: 83; 21.

(20) Ives, *48*, **8**: 551; 24. (21) Ives, *21*, **60**: 209; 24. (22) Kazda, *2*, **22**: 523; 23. (23) Kelly, *2*, **16**: 260; 20. (24) Koppius, *2*, **18**: 443; 21. (25) Krüger and Ehmer, *96*, **14**: 1; 23. (26) Küstner, *8*, **46**: 893; 15. (27) Kunz, *2*, **13**: 310; 19. (28) Kunz and Stebbins, *2*, **7**: 62; 16. (29) Kunz and Williams, *2*, **22**: 456; 23.

(30) Ladenburg, *88*, **9**: 165; 07. (31) Lenard, *8*, **8**: 149; 02. (32) Lienhop, *8*, **21**: 281; 06. (33) Ludlam, *3*, **23**: 757; 12. (34) Millikan, *2*, **7**: 355; 16. (35) Millikan and Souder, *197*, **2**: 19; 16. (36) Millikan and Winchester, *3*, **14**: 188; 07. (37) Nielsen, *2*, **22**: 525; 23. (38) Nielsen, *2*, **25**: 30; 25. (39) Obolensky, *8*, **39**: 961; 12.

(40) Palmer, *2*, **32**: 1; 11. (41) Partzsch and Hallwachs, *8*, **41**: 247; 13. (42) Piersol, *2*, **8**: 238; 16. (43) Piersol, *2*, **23**: 144; 24. (44) Pohl and Pringsheim, *88*, **12**: 697; 10. (45) Pohl and Pringsheim, *88*, **15**: 111; 13. (46) Pohl and Pringsheim, *63*, **14**: 1112; 13. (47) Pohl and Pringsheim, *88*, **16**: 336; 14. (48) Richardson and Compton, *3*, **24**: 575; 12. (49) Richardson and Rogers, *3*, **29**: 618; 15.

(50) Richtmyer, *2*, **29**: 71; 09. **30**: 385; 10. (51) Rohde, *8*, **19**: 935; 06. (52) Seiler, *21*, **52**: 129; 20. (53) Sende and Simon, *8*, **65**: 697; 21. (54) Serkof, *in* Hughes, *Photo-Electricity*. Cambridge, Cambridge Univ. Press, 1914. (55) Shinomiya, *21*, **49**: 303; 19. (56) Souder, *2*, **8**: 310; 16. (57) Stark, *63*, **10**: 614; 09. (58) Steubing, *63*, **10**: 787; 09. (59) Stuhlman, *2*, **13**: 109; 19.

(60) Stuhlman, *2*, **15**: 549; 20. (61) Tucker, *2*, **22**: 574; 23. (62) Varley and Unwin, *68*, **27**: 117; 07. (63) Volmer, *8*, **40**: 775; 13. (64) Welo, *3*, **45**: 593; 23. (65) Wiedmann and Hallwachs, *88*, **16**: 107; 14. (66) Williamson, *2*, **21**: 107; 23. (67) Young, *5*, **104**: 611; 23.

CRITICAL POTENTIALS OF ATOMS AND MOLECULES[1]

F. L. MOHLER

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When the molecules of a gas are bombarded by electrons possessing kinetic energy (Ve) the collisions are perfectly elastic unless V exceeds certain critical values V_e. At and above the velocities corresponding to these values V_e, an amount of energy eV_e can be lost in an inelastic collision, and this may be accompanied by the emission of radiation, or the energy may be dissipated in thermal agitation of the gas. If V equals or exceeds certain other critical values (V_I), ions are produced, *i.e.*, electrons are removed from the atomic structure. At every critical potential, the collisions are completely inelastic and the momentum given to the atom or molecule is negligible. Hence these values of V measure directly the energy expended in producing the resulting excitation or ionization. These critical potentials form the subject of this section.

From Bohr's quantum theory of radiation (Vol. I, p. 47, V, p. 392, 408, 409, 418 and VI, p. 23), $eV_I = h \times$ (limiting frequency of an absorption series), and $eV_e = h \times$ (frequency difference between the normal and another spectral term). The selection principles (Vol. V, p. 392 and VI, p. 23), which limit the combinations of terms that result in radiation, do not apply to excitation by collision, hence it is possible to produce states (called metastable) from which a radiating transition is impossible. A double excitation may result from a single collision if V is sufficiently great, and by increasing the current density of the electron stream, the same result may be obtained by successive collisions at a lower value of V.

In the case of atoms, the energy levels are determined solely by the electronic states, but in the case of molecules, a series of vibrational and rotational states is associated with each electronic state, and every change in electronic level is spontaneously accompanied by a change in vibration and rotation (3). Electrons probably can do directly no more than change the electronic state, and, if the spontaneous change in the state of vibration is small, the exciting potential will be nearly equivalent to the difference in the electronic energy levels. Such seems frequently to be the case, but there are many exceptions, and in some states the vibrational change is sufficient to cause spontaneous dissociation. The work of dissociation of a molecule into uncharged constituents is measured by the maximum vibrational energy that the molecule can have; *i.e.*, by the frequency limit of a vibration series. General references (17, 33, 36, 57, 97).

SYMBOLS

e, h, and λ have their usual significance (Vol. I, p. 16).

$D[D^+]$ Potential difference corresponding to work of dissociation of normal molecule (into uncharged atoms) [of molecule ion (into an uncharged and a charged atom)].

[1] Covers data to Nov. 1, 1927.

i	Current density of electron stream.
I	Ionization methods (17).
$I_M[I_A]$	Ionization potential of the molecule [of the atom].
IC	Method of inelastic collision (17).
PR	Method of positive-ray analysis for identification of ions (17).
R	Methods involving photoelectric effect and electron emission produced by excited atoms (17, 76).
S	Method of critical potential required for appearance of a spectral line or group (17).
V	Potential difference required to produce the effect considered.
$V_o[V_c]$	Observed [computed] value of V.
$V_I[V_{IC}]$	Value of V which corresponds to ionization [derived by method IC].
X	Holweck's method (49).
$\doteq$	Means "is equivalent to," or "corresponds to."
$(m_k)^n$	Indicates that there are n electrons in the valence shell defined by the quantum numbers m and k (*cf.* Vol. I, p. 48).
$[m_k]$	Indicates that one electron is removed from a shell defined by m and k. If the normal atom contains $(3_3)^{10}(4_1)$, then $[3_3]$ indicates that the resulting ion contains $(3_3)^9(4_1)$; (*cf.* Cu, Table 1).

The quantum numbers and series notation used in this report are as follows: (For additional information, *see* Vol. I, p. 47, V, p. 392 and VI, p. 23.

Alkali series*.....	1^2S	2^2S	2^2P_1	2^2P_2	3^2S
X-ray term†.....	K	L_I	L_{II}	L_{III}	M_I
Quantum number.....	1_1	2_1	2_2	2_2	3_1
Electrons‡.....	2	2	2	4	2

Alkali series*.....	3^2P_1	3^2P_2	3^2D_2	3^2D_3
X-ray term†.....	M_{II}	M_{III}	M_{IV}	M_V
Quantum number.....	3_2	3_2	3_3	3_3
Electrons‡.....	2	4	4	6

* Russells' notation. † Coster's notation. ‡ Number of electrons in completed group.

Useful Relations.—The relation between critical potentials (V) and wave number (ν = waves per cm in vacuum) or wave-length in vacuum (λ_0 expressed in Ångstrom) is $V = 1.2344\nu \times 10^{-4}$ volt $= 1.2344 \times 10^4/\lambda_0$ volt.

The relation between V for a reaction (ionization, dissociation) and the energy (E) of the reaction is $E/V = 2.307 \times 10^4$ (g-cal$_{20}$ per g-mole)/volt. For diatomic molecules of elementary substances $D + I_A = I_M + D^+$.

Table 1.—Critical Potentials of Atoms

In columns (1), (2), and (3) are symbol of the element and its atomic number, experimental method, and reference letter for following notes. λ_r = wave-length of resonance line of absorption spectrum. For other symbols, *see* above. Accuracy of V is roughly indicated by the number of significant figures. Unit of V_o and V_c = 1 volt; of λ_r = 1 Å = 10^{-8} cm.

(1)	(2)	(3)	V_o	Lit.	V_c*	Lit.	Transition	λ_r
A18....	IC		11.5	(42)	11.57	(106)	$3^1S - 4^1P$	1066.7
					11.77	(106)	$3^1S - 4^1P_2$	1048.2
	IC		13.0	(42)				
	IC		13.9	(42)				
	I	*a*	15.4	(42)	15.69	(106)	$M_{III}[3_2]$	
					15.86	(106)	$M_{II}[3_2]$	
	I	*b*	19.0	(20)				
	R		32.2	(81)				
	R	*c*	34.8	(81)				
	R		39.6	(81)				
	X		246.5	(49)			$L_{III}[2_2]$	

Arc spectrum at *a*, second spectrum at *b* if *i* is great, at *c* if *i* is small (20, 54). A third spectrum at 70 volt (20).

* From (33, 97) unless another source is indicated.

Table 1.—(*Continued*)

(1)	(2)	(3)	V_o	Lit.	V_c*	Lit.	Transition	λ_r
Ag47...	IC		3.1	(107)	3.65		$5^2S - 5^2P_2$	3383
					3.76		$5^2S - 5^2P_1$	3281
			6.0	(107)	7.54		$5^2S[5_1]$	
Al13....		*a*			5.96		$3^2P_1[3_2]$	
		b			10.0		$[3_1]$	
					18.17	(101)	3^1S Al$^+$	
					28.32	(96)	3^2S Al^{++}	
	X	*c*	68	(49)			$L_{III}[2_2]$	
b is from *a* + $3^1S - 3^3P_1$ of Al$^+$. *c* measured by absorption of soft X-rays in solid Al.								
As33...	IC		4.7	(100)				
	I		11.5	(100)			$4^4S[4_2]$	
Au79					4.61	(116)	$6^2S - 6^2P_2$	2676
					5.08	(116)	$6^2S - 6^2P_1$	2428
					9.25	(116)	$6^2S[6_1]$	
B5		*a*			8.34	(78)	$2^2P_1[2_2]$	
		b			11.92	(9)	$[2_1]$	
					24.2	(78)	2^1S B$^+$	
					37.79	(78)	2^2S B^{++}	
		c	192	(49)	176	(18)	$K[1_1]$	
b is computed from *a* + excitation potential of $(2^1S - 2^3P_1)$ of B$^+$. *c* is computed from K_α + *a*.								
Ba56...					1.56		$6^1S - 6^3P_1$	
					2.23		$6^1S - 6^1P$	
					5.19		$6^1S[6_1]$	
					9.96		6^2S Ba$^+$	
Ba → Ba^{++} requires 15.15 volt								
Be4....					9.50	(78)	$2^1S[2_1]$	
					18.14	(78)	2^2S Be$^+$	
Be → Be^{++} requires 27.6 volt								
Bi83....	IC	*a*	1.9	(100)	1.4			
					to			
					2.7			
	IC, S	*b*	3.9	(100)	4.02			3068
	IC, S	*c*	5.7	(100)	5.42			2277
					to			to
					5.98			2062
	I	*d*	8.0	(100)			$6^4S[6_2]$	
a gives metastable states. Resonance line and 4722 at *b*, group of lines at *c*, complete arc at *d*; second spectrum at 14 volt, third above 20 volt (100).								
C6.....		*a*			11.3	(78)	$2^3P_0[2_2]$	
					24.29	(78)	2^2P_1 C$^+$	
					45.5	(78)	2^1S C^{++}	
					64.23	(78)	2^2S C^{+++}	
	X	*b*	280.5	(49)	282	(18)	$K[1_1]$	
b computed from *a* + K_α								
Ca20...	IC		1.90	(86)	1.89		$4^1S - 4^3P_1$	6573
	IC		2.85		2.92		$4^1S - 4^1P$	4227
	I		6.01		6.09		$4^1S[4_1]$	
					11.82		4^2S Ca$^+$	
					24.5	(77)	$M_{III}[3_2]$	
					24.9	(77)	$M_{II}[3_2]$	
Ca → Ca^{++} requires 17.91 volt								
Cd48...	IC	*a*	3.95	(86)	3.78		$5^1S - 5^3P_1$	3261
	IC	*b*	5.35		5.39		$5^1S - 5^1P$	2289
	I	*c*	9.0		8.95		$5^1S[5_1]$	
		d			16.84	(105)	5^2S Cd$^+$	
Resonance lines at *a* and *b*, complete arc at *c* (72). Spectrum of Cd$^+$, *i* great, at *d* (99). Cd → Cd^{++} requires 25.8 volt.								
Cl17....	X		203	(49)			$L_{III}[2_2]$	
Measured in HCl								
Co27...		*a*			8.25	(102)	$^4F[4_1]$	
		b			16.8	(102)	^5F Co$^+$	
Normal Co is $(3_3)^7(4_1)^2$; *b* gives $(3_3)^7$, but normal Co$^+$ is $(3_3)^8$, and the lowest ionization potential involves the double transition $(3_3)^7(4_1)^2 \rightarrow (3_3)^8$, requiring 7.81 volt. $(3_3)^8 \rightarrow (3_3)^7$ requires 17.2 volt (102).								
Cr24...		*a*			6.74	(14)	$^7S[4_1]$	
		b			8.24	(65)	$^5D[3_3]$	
		c			16.6	(102)	^6S Cr$^+$	
Normal Cr is $(3_3)^5(4_1)$; *a* gives $(3_3)^5$, *b* gives $(3_3)^4(4_1)$, *c* $(3_3)^5 \rightarrow (3_3)^4$.								
Cs55...	IC	*a*	1.48	(32)	1.38		$6^2S - 6^2P_2$	8943
					1.45		$6^2S - 6^2P_1$	8521
	I	*b*	3.9	(32)	3.88		$6^2S[6_1]$	
	R	*c*	13.0	(81)				
	R		18.5	(81)				
	R, S	*d*	21.5	(81)				
	R		39.0	(81)				
Resonance lines at *a*, $6S - 7P$ at 2.7 volt, $6S - 8P$ and $6P - 8S$ at 3.2 volt, complete arc *b* (93). Spectrum of Cs$^+$ at *c* if *i* is great, at *d* if *i* is small. Third spectrum at 55 volt if *i* is small (81).								

TABLE 1.—(*Continued*)

(1)	(2)	(3)	V_o	Lit.	V_c*	Lit.	Transition	λ_r
Cu29...		*a*			1.38	(108)	$4^2S - 3^2D$	
					3.77		$4^2S - 4^2P_2$	3274
					3.80		$4^2S - 4^2P_1$	3248
	I	*b*	7.8	(107)	7.69		$4^2S[4_1]$	
		c			10.44	(109)	$MV[3_3]$	
		d			20.5	(109)	$Cu^+ \rightarrow Cu^{++}$	
Normal Cu contains $(3_3)^{10}(4_1)$; *a* gives $(3_3)^9(4_1)^2$; *d* $(3_3)^9$. $Cu \rightarrow Cu^{++}$ requires 28.2 volt.								
F9.....		*a*			16.9	(78)	$2^2P[2_2]$	
					32	(78)	2^2P F^+	
	X	*b*	684	(49)	689	(1)	$K[1_1]$	
				b from $K_\alpha + a$				
Fe26...		*a*			7.83	(102,119)	$^5D[4_1]$	
		b			16.5	(102)	^6D Fe^+	
Normal Fe contains $(3_3)^6(4_1)^2$, *b* gives $(3_3)^6$.								
Ga31...	IC		3.07	(58)	3.06		$4^2P_1 - 5^2S$	4033
	IC		4.22	(58)	4.29		$4^2P_1 - 4^2D$	2874
	I		5.80	(58)	5.97		$4^2P_1[4_2]$	
	I		13.2	(58)			$[4_1]$	
	I				30.59	(13)	4^2S Ga^{++}	
There is one IC value not related to known spectrum (58).								
Ge32...					45.51	(13)	4^2S Ge^{+++}	
H1.....	R	*a*		†	10.15		$N\left(1 - \frac{1}{2^2}\right)$	1216
	R			†	12.03		$N\left(1 - \frac{1}{3^2}\right)$	1026
	R			†	12.69		$N\left(1 - \frac{1}{4^2}\right)$	973
	R			†	13.00		$N\left(1 - \frac{1}{5^2}\right)$	950
	R			†	13.16		$N\left(1 - \frac{1}{6^2}\right)$	938
	R			†	13.26		$N\left(1 - \frac{1}{7^2}\right)$	931
	R	*b*		†	13.54		$N[1_1]$	
Complete arc spectrum at *b* if *i* is small, at *a* if *i* is great (23).								
He2....	R, IC	*a*	19.75	(34.5, 37)	19.73	(69)	$1^1S - 2^3S$	
	R, IC		20.55	(34.5, 37)	20.55	(69)	$1^1S - 2^1S$	600.5
	R, IC		21.2	(34.5, 37)	21.12	(69)	$1^1S - 2^1P$	584.4
	R, IC	*b*	22.9	(34.5, 37)	22.98	(69)	$1^1S - 3^1P$	537.1
	I	*c*	24.6	(34.5, 37)	24.48	(69)	$1^1S[1_1]$	
		d			54.16		$4N$ He^+	
	I, S	*e*	78.8	(34.5, 37)	78.64		$He \rightarrow He^{++}$	
Arcs strike at *a* if *i* is great (16). Near *b* lines $2P - 3S$, $2P - 3D$, and $2S - 3P$, both singlets and triplets, appear. Complete arc spectrum at *c* (43). Line 4686 of He^+ excited at *d* if *i* is great and at *e* if *i* is small (19).								
Hg80...	IC, R	*a*	4.68	(35)	4.66		$6^1S - 6^3P_0$	
	IC, R		4.90	(35)	4.86		$6^1S - 6^3P_1$	2537
	IC, R		5.47	(35)	5.43		$6^1S - 6^3P_2$	
	IC, R		6.73	(35)	6.67		$6^1S - 6^1P$	1850
	IC, R	*b*	7.73	(35)	7.69		$6^1S - 7^3S$	
	IC, R		8.64	(35)	8.58		$6^1S - 7^3P_1$	1436
	IC, R		8.86	(35)	8.79		$6^1S - 7^1P$	1403
	I	*c*	10.40	(67)	10.39		$6^1S[6_1]$	
	PR	*d*	19	(110)	18.97	(13)	6^2S Hg^+	
Other R values, not related to known spectrum, are found (35). Resonance line at *a*, $6^3P - 7^3S$ and $6^3P_1 - 7^1S$ near *b*, complete arc spectrum at *c* (43). Second spectrum near *d*, third spectrum at 24 volt, and fourth at 57 volt (28).								
I53.....	I		8.0	(112)			$5^2P[5_2]$	
Measured in thermally dissociated vapor								
In49....	IC		0.30	(58)	0.27		$5^2P_1 - 5^2P_2$	
	IC		3.03	(58)	3.01		$5^2P_1 - 6^2S$	4102
	IC		4.07	(58)	4.06		$5^2P_1 - 5^2D$	3039
	I		6.3	(58)	5.76		$5^2P_1[5_2]$	
	I		14.1	(58)			$[5_1]$	
					27.86	(13)	5^2S In^{++}	
K19....	IC	*a*	1.55	(115)	1.60		$4^2S - 4^2P_2$	7699
					1.61		$4^2S - 4^2P_1$	7665
	I	*b*	4.1	(115)	4.32		$4^2S[4_1]$	
	R, I	*c*	19	(79)				
	R		23.8	(81)				
	R, S	*d*	31.8	(81)				
	R		48.0	(81)				
Resonance lines at *a*, $4S - 5P$ at 3.3 volt, $4P - 4D$ and $4P - 6S$ at 3.7, and $4S - 6P$ at 3.9 volt; complete arc spectrum at *b* (91). Spectrum of K^+ at *c* if *i* is great, at *d* if *i* is small (79).								

* From, (33, 97) unless another source is indicated.

† Values observed in gas thermally dissociated differed from those computed by ±0.05 volt and are entirely different from values for ordinary (H_2) hydrogen (95).

TABLE 1.—(*Continued*)

(1)	(2)	(3)	V_o	Lit.	V_c*	Lit.	Transition	λ_r
Kr36...	IC		9.9	(44)				
	IC		10.5	(44)				
	IC		11.5	(44)				
	IC		12.1	(44)				
	I	*a*	13.3	(44)			$N_{III}[4_2]$	
	I	*b*	15.5	(20)				
	I	*c*	28.2	(20)				
Arc spectrum at *a*, second spectrum at *b* with high pressure and at *c* with low, third spectrum at 59 volt (20).								
Li3.....					1.84		$2^2S - 2^2P$	6708
		a			5.37		$2^2S[2_1]$	
	R	*b*	54	(79)				
Arc spectrum at *a*, 2934 at *b* (79)								
Mg12..	IC	*a*	2.65	(86)	2.70		$3^1S - 3^3P_1$	4571
	IC	*b*	4.42	(86)	4.33		$3^1S - 3^1P$	2852
	I	*c*	7.75	(86)	7.61		$3^1S[3_1]$	
	S	*d*	15	(30)	14.97		3^2S Mg^+	
	R		46	(83)	45.8	(77)	$L_{III}[2_2]$	
					46.1	(77)	$L_{II}[2_2]$	
Resonance lines at *a* and *b*; complete arc spectrum at *c*; spectrum of Mg^+ at *d* if *i* is great (30). With *i* small, Mg^+ lines $3S - 3P$ at 12 volt, $3P - 4S$ and $3P - 3D$ at 16, and $3D - 4F$ at 19 volt (98). These equal *c* + exciting potentials of Mg^+. $Mg \rightarrow Mg^{++}$ requires 22.58 volt.								
Mn25..		*a*			7.40	(15)	$^6S[4_1]$	
		b			15.7	(40, 102)	^7S Mn^+	
Normal Mn contains $(3_3)^5(4_1)^2$; *a* gives $(3_3)^5(4_1)$; *b*, $(3_3)^5$.								
Mo42..		*a*			7.35	(59)	$^7S[5_1]$	
Normal Mo contains $(4_3)^5(5_1)$ *a* gives $(4_3)^5$.								
N7.....					14.48	(52)	$2^4S[2_2]$	
					29.56	(78)	2^3P_0 N^+	
					47.2	(78)	2^3P_1 N^{++}	
	X		397	(49)			$K[1_1]$	
Na11...	IC	*a*	2.19	(115)	2.09		$2^2S - 2^2P_2$	5896
							$2^2S - 2^2P_1$	5890
	I	*b*	5.13		5.12		$2^2S[3_1]$	
	R, I	*c*	35 ± 2	(79)				
	S	*d*	44 ± 2	(79)				
Resonance lines at *a*, $3S - 4P$ at 4, $3P - 5S$ at 4.4, $3P - 4D$ at 4.6 volt, and complete arc spectrum at *b* (90); second spectrum at *c* if *i* is great, at *d* if *i* is small (79).								
Ne10...	IC		16.65	(42)	16.60	(70)	$2^1S - 3^1P_1$	743.8
					16.77	(70)	$2^1S - 3^3P_2$	735.9
	IC	*a*	18.45	(42)	18.42	(70)		
	I	*b*	21.5	(42)	21.47	(70)	$L_{III}[2_2]$	
					21.57	(70)	$L_{II}[2_2]$	
		c	(33.4)					
	R	*d*	48	(81)				
	R	*e*	54.9	(81)				
Paschen's lines $1s - 2p$ excited near *a* and complete arc spectrum at *b* (43). Second spectrum between *d* and *e* if *i* is small (5.5, 81). $c = e - b$.								
Ni28...		*a*			8.65	(102, 109)	$^3F[4_1]$	
		b			17.15	(102)	^4F Ni^+	
Normal Ni is $(3_3)^8(4_1)^2$; *b* gives $(3_3)^8$, but normal Ni^+ is $(3_3)^9$, and the lowest ionizing potential involves the double transition $(3_3)^8(4_1)^2 \rightarrow (3_3)^9$, requiring 7.64 volt. $(3_3)^9 \rightarrow (3_3)^8$ requires 18.2 volt.								
O8.....		*a*			13.56	(51)	$2^3P[2_2]$	
					35.0	(78)	2^4S O^+	
					54.8	(78)	2^3P_0 O^{++}	
					77.0	(78)	2^2P O^{+++}	
	X	*b*	528	(49)	510	(18)	$K_1[1_1]$	
				b from $K_\alpha + a$				
P15....					19.82	(7)	3^3P_0 P^+	
					30.04	(9)	3^2P_1 P^{++}	
					64.74	(8)	3^2S P^{++++}	
	R		126	(83)			$L_{III}[2_2]$	
Pb82...	IC	*a*	1.26	(87)	0.96	(39)		
					to			
					2.6			
			7.9	(87)	7.38	(39)	$6^3P_0[6_2]$	
					43.7	(13)	6^2S Pb^{+++}	
				a gives $6^3P_{1,2}$, 6^1D, and 7^1S				
Pd46...		*a*			9.5	(66, 109)	$^1S[4_3]$	
Normal Pd contains $(4_3)^{10}$, *a* gives $(4_3)^9$.								
Rb37...	IC	*a*	1.6	(32)	1.55		$5^2S - 5^2P_2$	7948
					1.58		$5^2S - 5^2P_1$	7800
	I	*b*	4.1	(32)	4.16		$5^2S[5_1]$	
	R, I	*c*	16.0	(79)				
	R		21.6	(79)				
	R	*d*	25.2	(79)				
Resonance lines at *a*, complete arc spectrum at *b* (92). Spectrum of Rb^+ at *c* with *i* great, at *d* with *i* small (79).								

TABLE 1.—(*Continued*)

(1)	(2)	(3)	V_o	Lit.	V_c*	Lit.	Transition	λ,
S16....					10.31	(50)	$3^3P[3_2]$	
					47.08	(9)	3^2P_1 S^{+++}	
					87.68	(10)	3^2S S^{+++++}	
	X	*a*	163	(49)			$L_{III}[2_2]$	
			a measured in H_2S					
Sc21....		*a*			6.57	(102,104)	$^2D[4_1]$	
		b			12.80	(102,104)	^3D Sc^+	
					25.1	(38)	^2D Sc^{++}	
Normal Sc has $(3_3)(4_1)^2$; *a* gives $(3_3)(4_1)$, *b* gives (3_3).								
Se34....	I		12.7	(118)			$4^3P[4_2]$	
Measured in vapor which was not purely monatomic								
Si14....					7.94	(73)	$3^3P_0[3_2]$	
					16.27	(34)	3^2P_1 Si^+	
					31.66	(34)	3^1S Si^{++}	
					44.95	(34)	3^2S Si^{+++}	
	X	*a*	98	(49)			$L_{III}[2_2]$	
			a measured in SiH_4					
Sn50...					7.30	(74)	$5^3P_0[5_2]$	
					14.5	(89)	5^2P_1 Sn^+	
					40.40	(13)	5^2S Sn^{+++}	
Sr38....					1.79		$5^1S - 5^3P_1$	6893
					2.68		$5^1S - 5^1P$	4607
					5.67		$5^1S[5_1]$	
					10.98		5^2S Sr^+	
$Sr \rightarrow Sr^{++}$ requires 16.65 volt								
Ti22....		*a*			6.80	(102)	$^3F[4_1]$	
		b			13.60	(102)	^4F Ti^+	
					28	(103)	^3D Ti^{++}	
					43.1	(103)	^2D Ti^{+++}	
Normal Ti has $(3_3)^2(4_1)^2$, *b* gives $(3_3)^2$.								
Tl81....	IC		0.9	(88)	0.96		$6^2P_1 - 6^2P_2$	
		a			3.27		$6^2P_1 - 7^2S$	3776
		b			4.47		$6^2P_1 - 6^2D$	2768
	I	*c*	6.04	(88)	6.08		$6^2P_1[6_2]$	
	R	*d*	12.0	(88)			$[6_1]$	
					30.62	(13)	6^2S Tl^{++}	
Resonance line and $(6^2P_2 - 7^2S)$ at *a*; resonance line and $(6^2P_2 - 6^2D)$ at *b*; complete arc spectrum at *c*. Second spectrum at *d* (88).								
V23....		*a*			7.04	(75, 102)	$^4F[4_1]$	
		b			14.4	(102)	^5F V^+	
					68.70	(38)	^2D V^{++++}	
Normal V is $(3_3)^3(4_1)^2$; *b* gives $(3_3)^3$, but normal V^+ is $(3_3)^4$, and the lowest ionization potential involves the double transition $(3_3)^3(4_1)^2 \rightarrow (3_3)^4$, requiring 6.76 volt. $(3_3)^4 \rightarrow (3_3)^3$ requires 14.7 volt (102).								
Xe54...	IC		8.3	(44)				
	IC		9.9	(44)				
	IC		11.0	(44)				
	I	*a*	11.5	(44)			$O_{III}[5_2]$	
	I	*b*	13.0	(20)				
	I	*c*	24.2	(20)				
Arc spectrum at *a*; second at *b* if pressure is high, at *c* if pressure is low; third spectrum at 51 volt (20).								
Yt39...					20.40	(10)	^2D Yt^{++}	
Zn30...	IC	*a*	4.18	(86)	4.01		$4^1S - 4^3P_1$	3076
	IC	*b*	5.65	(86)	5.77		$4^1S - 4^1P$	2139
	I	*c*	9.3	(86)	9.35		$4^1S[4_1]$	
					17.89	(105)	4^2S Zn^+	
Resonance lines at *a* and *b*. $(4^3P - 5^3S)$ below *c*; complete arc spectrum at *c* (43). $Zn \rightarrow Zn^{++}$ requires 27.2 volt.								
Zr40....					34.17	(10)	^2D Zr^{+++}	

* From (33, 97) unless another source is indicated.

TABLE 2.—CRITICAL POTENTIALS OF MOLECULES

Unit of V and D = 1 volt

	V_I	V_{IC}	Lit.		V_I	V_{IC}	Lit.
Br_2*	12.8		(71)	HCl‡	13.75		(61,
Cl_2*	13.2		(71)				71)
H_2....	*See* Tab. 3				23.5		(80)
				HBr‡..	13.25		(61,
I_2†....	10.1	2.3	(84)				71)
				HI‡...	12.75		(61,
N_2....	*See* Tab. 3						71)
O_2....	*See* Tab. 3			H_2S...	10.4		(71)
P_x....	13.3	5.8	(82)	NO....	*See* Tab. 3		
S_x.....	12.2	4.8	(82)	NH_3...	11.1		(71)
H_2O...	13.2		(71)	CO....	*See* Tab. 3		

TABLE 2.—(*Continued*)

Molecule	V_I	V_{IC}	Lit.
$CHCl_3$, Chloroform	11.5	6.5	(6)
HCN, Hydrocyanic acid	14.8		(61)
CH_4, Methane	14.4		(88.1)
C_2N_2, Cyanogen	16.3		(88.1)
C_2H_2, Acetylene	12.3		(88.1)
C_2H_4, Ethylene	11.5		(88.1)
C_2H_6, Ethane	12.8		(88.1)
$C_4H_{10}O$, Ethyl ether	13.6	6.6	(6)
C_6H_6, Benzene	9.6	6.0	(6)
C_7H_8, Toluene	8.5	6.2	(6)
C_8H_{10}, Xylene	10.0	6.5	(6)
$HgCl_2$, Mercuric chloride	12.1		(31)
$ZnCl_2$, Zinc chloride	12.9		(31)

* Assuming that the vibration series limits measure the work of dissociation into a normal and an excited atom, the excited state being $^2P_1$ (117), D_{Cl_2} = 2.47, D_{Br_2} = 1.96, D_{I_2} = 1.53; thermochemical data give 2.47, 2.00, and 1.50, respectively (27, 64).

† Near V_{IC} visible band spectrum is excited; near V_I, the ultra-violet bands and first atomic line spectrum; at 21.0 volt, second line spectrum (84). For *D*, *see* preceding note.

‡ These values of V_I are almost exactly the computed values for dissociation of HR into H^+ and R^-, but PR shows (2) that for HCl the primary product is HCl^+, and this is confirmed by data for production of negative ions in HCl (80)

TABLE 3.—CRITICAL POTENTIALS OF H_2, N_2, O_2, NO AND CO

			V_o	Lit.	V_c	Bands	Lit.
H_2.....	IC, R		10.8 ± 0.3	(55, 63, 94)	11.15	Dieke-Hopfield	(22)
	IC, R	*a*	12.4 ± 0.4		12.2	Dieke-Hopfield	(22)
	I, PR	*b*	15.9 ± 0.15		15.3	H_2^+	(3.1)
	I		29.4				
Questionable evidence for one or two intermediate values of V_o. Near *a* continuous spectrum (55). Molecular line-spectrum in two stages, one just below *b*, one above *b*. Atomic lines below *b* (24). PR indicates that at and above *b* only H_2^+ is produced directly, and that H^+ and H_3^+ arise from collisions of H_2^+ with H_2 (45, 111); but collisions of electrons with H_2 do directly produce H (56) and atomic radiation (5). From vibration series of normal state (22, 120), D = 4.36. Electron collisions cause dissociation at V = 11.5. †Dissociation by absorption of light occurs at a frequency $\backsimeq$ V = 14.53; if one atom is left in the first excited state, V = 4.36 + 10.15 (Table 1) = 14.51. $D^+(= D + I_A - I_M)$ = 4.36 + 13.54 − 15.3 = 2.6 volt.							
N_2*.....	IC, R, S	*a*	8.12 ± 0.1	(11, 26, 60, 82, 113)	8.52	Birge-Hopfield	(114)
	S	*b*	9.5		9.47	First positive (*b-a*)	(3)
	S	*c*	13.0 ± 1.0		13.13	Second positive (*c-b*)	(3)
	S	*d*	15.0		14.93	Fourth positive (*d-b*)	(3)
	I, S, PR	*e*	16.7 ± 0.3			N_2^+	(46)
	S	*f*	19.6		19.85	First negative (*f-e*)	(3)
	R		24.6				
	R		29.9				
Atomic lines are directly excited (62) near V = 32. From vibration series of *a* (4), $D = a + 3.9$ = 12.0. Assuming afterglow of active nitrogen is from excitation of N_2 by recombining atoms (113), $D = a + 3.4$ = 11.5. From N_2^+ spectrum, D^+ = 9.06, whence $D(= D^+ + I_M - I_A)$ = 9.06 + 16.7(*e*) − 14.48 (Table 1) = 11.3. Mean D = 11.6 (4). Minimum potential to give N^+ is $I_M + D^+$ = 25.8. PR indicates that only N_2^+ is produced directly, but by collisions of N_2^+ and N_2, N^+ is formed near theoretical voltage (46).							
O_2.....					6.10	Schumann	(3)
	IC	*a*	7.9				
	I, PR	*b*	12.8	(47, 71)	14.1	O^+	
	I, PR	*c*	15.8	(71, 82)			
	S	*d*	19.2	(68)	18.8	First negative (*d-b*)	(3)
	S, PR	*e*	19.8	(68)	20.6	O^+	(47)
	S		21.0	(68)		Schuster	(3)
Observations by I are discordant; may be two processes: Direct dissociation (*c*) giving ions in high vibrational state, and production of excited molecules (*b*) which, by molecular collisions, give ions in zero vibrational state. At (*e*), atom ions (47) and atomic lines are produced by direct collision (68), $e = D + I_A$. Vibration series gives accurately (4) D = 7.05; dissociation by absorption occurs here with position of maximum of absorption $\backsimeq$ 8 volt ($\backsimeq$ *a*(?)). From spectral data, D^+ = 6.5, which may be too low; $I_M(= I_A + D - D^+) \gtrsim 13.56 + 7.05 - 6.5 \gtrsim$ 14.1.							
NO.....					5.44	Gamma	(3)
					5.60	Beta	(3)
	I		9.4	(71)		NO^+	(48)
	PR	*a*	21	(48)	21.5	O^+	
	PR	*b*	22	(48)	22.4	N^+	
From vibrational states of normal level (4), D = 7.9; from thermochemical data and D for O_2 and N_2, D = 8.3. $a = D_{NO} + I_A$ for O; $b = D_{NO} + I_A$ for N.							

* Values of V_c are based on value of V_o at *a*.

TABLE 3.—(*Continued*)

			V_o	Lit.	V_e	Bands	Lit.
CO.....	IC	*a*	5.8	(85)	5.97	Cameron	(53)
					7.27		
	IC	*b*	8.0	(85)	7.99	Fourth positive	(53)
	R, S	*c*	10.15*	(25, 41)	10.34	Third positive (*c-a*)	(53)
	S	*d*	10.7*	(25, 41)	10.72	Ångstrom (*d-a*)	(53)
	S	*e*	11.1	(25)	11.34	(*e-b*)	
	I	*f*	14.2*	(25, 41)			
	S	*g*	16.8*	(25, 41)	16.7	Comet-tail (*g-f*)	(53)
	S	*h*	19.9*	(25, 41)	19.8	First negative (*h-f*)	(53)

Three other spectroscopic levels between *e* and *f*. From vibrational states of normal level (4), $D = 11.2$; from heat of combustion and D for O_2, $D = 10.8$; mean $D = 11.0$. From vibrational states, $D^+ = 9.8$. As $I_A(= I_M + D^+ - D) = 14.2(f) + 9.8 - 11.0 = 13.0$ is, within experimental error, $= I_A$ of O (= 13.56, Table 1), the dissociation of CO^+ probably gives C and O^+.

* Mean error = ±0.1.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bäcklin, Siegbahn and Thoraeus, *3*, **49**: 513; 25. (2) Barton, *2*, **29**: 608; 27. (3) Birge, *337*, No. **69**; 26. (3.1) Birge, *197*, **14**: 12; 28. (4) Birge and Sponer, *2*, **28**: 259; 26. (5) Blackett and Franck, *96*, **34**: 389; 25. (5.5) Bloch, Bloch and Déjardin, *34*, **180**: 731; 25. (6) Boucher, *2*, **19**: 189; 22. (7) Bowen, *2*, **29**: 749; 27. (8) Bowen and Millikan, *2*, **25**: 295; 25. (9) Bowen and Millikan, *2*, **26**: 150; 25.

(10) Bowen and Millikan, *2*, **28**: 923; 26. (11) Brandt, *96*, **8**: 32; 21. (12) Bruin, *58*, **119**: 925; 27. (13) Carroll, *62*, **225**: 357; 26. (14) Catalán, *34*, **176**: 84, 247, 1063; 23. (15) Catalán, *62*, **223**: 127; 23. (16) Compton, *3*, **40**: 553; 20. (17) Compton and Mohler, *337*, No. **48**; 24. (18) Dauvillier, *51*, **8**: 1; 27. (19) Davies, *5*, **100**: 599; 22.

(20) Déjardin, *16*, **2**: 241; 24. (22) Dieke and Hopfield, *2*, **30**: 400; 27. (23) Duffendack, *2*, **20**: 665; 22. (24) Duffendack, *21*, **60**: 122; 24. (25) Duffendack and Fox, *166*, **64**: 277; 26. (26) Duncan, *21*, **62**: 145; 25. (27) Dymond, *96*, **34**: 553; 25. (28) Eldridge, *2*, **29**: 213; 27. (29) Ellsworth and Hopfield, *2*, **29**: 79; 27.

(30) Foote, Meggers and Mohler, *3*, **42**: 1002; 21. (31) Foote and Mohler, *2*, **17**: 394; 21. (32) Foote, Rognley and Mohler, *2*, **13**: 59; 19. (33) Fowler, *Report on series in line spectra*. London, Fleetway Press, 1922. (34) Fowler, *62*, **225**: 1; 25. (34.5) Franck, *96*, **11**: 155; 22. (35) Franck and Einsporn, *96*, **2**: 18; 20. (36) Franck and Jordan, *Anregung von Quantensprüngen durch Stösse*. Berlin, J. Springer, 1926. (37) Franck and Knipping, *96*, **1**: 320; 20. (38) Gibbs and White, *197*, **12**: 448; 26. (39) Grotrian, *96*, **18**: 169; 23.

(40) Hartree, *58*, **116**: 356; 25. (41) Hepburn, *2*, **29**: 212; 27. (42) Hertz, *96*, **18**: 307; 23. (43) Hertz, *96*, **22**: 18; 24. (44) Hertz and Kloppers, *96*, **31**: 463; 25. (45) Hogness and Lunn, *2*, **26**: 44; 25. (46) Hogness and Lunn, *2*, **26**: 786; 25. (47) Hogness and Lunn, *2*, **27**: 732; 26. (48) Hogness and Lunn, *2*, **30**: 26; 27. (49) Holweck, *De la lumière aux rayons X*. Recueil des Conférences-rapports de documentation sur la physique, 1927.

(50) Hopfield, *2*, **22**: 523; 23. (51) Hopfield, *21*, **59**: 114; 24. (52) Hopfield, *2*, **27**: 801; 26. (53) Hopfield and Birge, *2*, **29**: 922; 27. (54) Horton and Davies, *5*, **102**: 131; 22. (55) Horton and Davies, *3*, **46**: 872; 23. (56) Hughes and Skellett, *2*, **30**: 11; 27. (57) Hund, *B1*. (58) Jarvis, *2*, **29**: 442; 27. (59) Kiess, *31A*, **19**: 113; 23.

(60) Kneser, *8*, **79**: 597; 26. (61) Knipping, *96*, **7**: 328; 21. (62) Kondratjev, *96*, **38**: 346; 26. (63) Krüger, *3*, **64**: 288; 21. (64) Kuhn, *96*, **39**: 77; 26. (65) Laporte, *96*, **39**: 123; 26. (66) Laporte, *48*, **13**: 1; 26. (67) Lawrence, *2*, **28**: 947; 26. (68) Lockrow, *21*, **63**: 205; 26. (69) Lyman, *21*, **60**: 1; 24.

(70) Lyman and Saunders, *58*, **116**: 358; 25. (71) Mackay, *2*, **24**: 319; 24. (72) McLennan and Ireton, *3*, **36**: 461; 18. (73) McLennan and Shaver, *69*, **18 III**: 1; 24. (74) McLennan, Young and McLay, *69*, **18 III**: 57; 24. (75) Meggers, *128*, **13**: 317; 23. (76) Messenger, *2*, **28**: 962; 26. (77) Millikan and Bowen, *2*, **23**: 1; 24. (78) Millikan and Bowen, *197*, **13**: 531; 27. (79) Mohler, *31A*, **20**: 167; 25.

(80) Mohler, *2*, **26**: 614; 25. (81) Mohler, *2*, **28**: 46; 26. (82) Mohler and Foote, *31A*, **16**: 669; 20. (83) Mohler and Foote, *31A*, **17**: 471; 22. (84) Mohler and Foote, *2*, **21**: 382; 23. (85) Mohler and Foote, *2*, **29**: 141; 27. (86) Mohler, Foote and Meggers, *31A*, **16**: 725; 20. (87) Mohler, Foote and Stimson, *31A*, **15**: 723; 20. (88) Mohler and Ruark, *48*, **7**: 819; 23. (88.1) Morris, *2*, **32**, 456; 28. (89) Narayan and Rao, *58*, **120**: 120; 27.

(90) Newman, *3*, **50**: 165; 25. (91) Newman, *3*, **50**: 796; 25. (92) Newman, *3*, **50**: 1276; 25. (93) Newman, *3*, **1**: 705; 26. (94) Olmstead, *2*, **20**: 613; 22. (95) Olmstead and Compton, *2*, **22**: 559; 23. (96) Paschen, *8*, **71**: 142; 23. (97) Paschen and Götze, *Seriengesetze der Linienspektren*. Berlin, J. Springer, 1922. (98) Ruark, *48*, **11**: 199; 25. (99) Ruark and Chenault, *48*, **10**: 653; 25.

(100) Ruark, Mohler, Foote and Chenault, *31A*, **19**: 463; 24. (101) Russell, *58*, **113**: 163; 24. (102) Russell, *21*, **66**: 184; 27. (103) Russell and Lang, *21*, **66**: 13; 27. (104) Russell and Meggers, *31A*, **22**: 329; 27. *2*, **29**: 606; 27. (105) v. Salis, *8*, **76**: 145; 25. (106) Saunders, *197*, **12**: 556; 26. (107) Shenstone, *58*, **112**: 100; 23. (108) Shenstone, *2*, **28**: 449; 26. (109) Shenstone, *2*, **29**: 380; 27.

(110) Smyth, *5*, **102**: 283; 22. (111) Smyth, *2*, **25**: 452; 25. (112) Smyth and Compton, *2*, **16**: 501; 20. (113) Sponer, *96*, **34**: 622; 25. (114) Sponer, *197*. **13**: 100; 27. (115) Tate and Foote, *3*, **36**: 64; 18. (116) Thorsen, *218*, **11**: 500; 23. (117) Turner, *2*, **27**: 397; 26. (118) Udden, *2*, **18**: 385; 21, (119) Walters, *48*, **8**: 245; 24.

(120) Witmer, *2*, **28**: 1223; 26.

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INTRODUCTION

The dielectric constant (ϵ) of a material is a measure of the ratio of the electric displacement (D) to the electric field intensity (E), $D = \epsilon E/4\pi$; for a vacuum, $\epsilon = 1$ cgse unit. The value of ϵ may be determined from the measurements (1) of electrical capacities, (2) of mechanical forces between charged conductors, or (3) of the wave lengths of electrical waves. All three methods yield the same result, except in so far as the value of ϵ varies with the frequency (ν) of E. If electrical waves experience absorption in the substance, the index of the absorption (*v.* Vol. 1, p. 34) being k', then $\epsilon = (1 - k'^2)\lambda_0^2/\lambda^2$, where $\lambda_0[\lambda]$ = wave-length, for frequency ν, in vacuum [in substance]; values of ϵ so obtained are accompanied by the corresponding values of k', if known; when k' is not given, it is believed to be too small to affect the value of ϵ within the stated limits of accuracy.

For variation of ϵ with E, *v.* p. 106; with magnetic field, *v.* p. 105; with illumination, *v.* p. 79.

The dielectric strength (S) of a material is defined as the minimum value, in the material, of the electric field intensity (E) at which a disruptive discharge occurs. In many cases it appears

doubtful if S is a constant, characteristic of the material, as it frequently appears to vary with the nature of the electrodes and with the distance between them. As the determination of the actual maximum value of E occurring in the field at the instant of discharge is difficult, the value of S is frequently merely indicated by stating the kind of electrodes, the minimum distance (l) between their surfaces, and the difference in their potentials at the instant of discharge, if the difference is increasing slowly and continuously (D.C.). If the voltage is alternating (A.C.) either the effective (V_e) or the maximum (V_m) value of the alternating potential difference of the electrodes is stated. If the potential difference varies as sin ωt, $V_m = 1.414V_e$. Electrical oscillations in the circuit may introduce serious errors and injure connected apparatus, and should be prevented from reaching the terminals by the insertion, in series with each terminal, of a non-inductive resistance of at least one ohm per volt. The effect of surrounding objects in modifying the electrical field must be considered, and very definite specifications for the construction of the gap must be followed if accurate values for the potential difference corresponding to a given spark length are desired (*cf.* p. 79, 80).

DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF ELEMENTARY SUBSTANCES, PURE INORGANIC COMPOUNDS, AND AIR

H. L. Curtis and F. M. Defandorf

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Symbols.—l = liquid, s = solid, t_R = room temperature, $v.p.$ = vapor pressure of the saturated vapor at the temperature indicated. ϵ = dielectric constant, ν = frequency of field used in obtaining ϵ. Such expressions as "(80 p 160)" and "(10° t 100°)" indicate that the accompanying coefficients apply so long as p [t] lies between 80 and 160 [10° and 100°]; "25; 45" in the temperature column indicates that the same value was found at 25° as at 45°. Other symbols unexplained in Vol. I, p. 16, will be defined where used.

No data have been found for the dielectric strength of any solid or liquid included in this section.

Table 1.—Dielectric Constant (ϵ) of Pure Inorganic Gases

$(\epsilon_t - 1) = (\epsilon_0 - 1)[1 + \alpha t(10)^{-3} + \beta t^2(10)^{-6}]$; $\epsilon - 1 = (ap + bp^2)(10)^{-4} = 3cd_1[1 + cd_1(10)^{-6}](10)^{-6}$, where d_1 = specific gravity of the gas with reference to itself at 0°C and 1 atmosphere. $\epsilon = 1 + 0.001\Delta$; $\nu = A \times 10^n$. Unit of ϵ = 1 cgse unit; of p = 1 atmosphere; of ν = 1 cycle/sec; of t = 1°C.

	$\Delta_{t,p}$	t	p	A	n	Lit.
A	0.56	0	1	1	6	(15)
Br	12.8	180	1	Radio		(14)
H	0.26	0	1	≤2	6	(5, 12, 49, 75, 96, 151)
	0.928	−185	1	Radio		(106)
	c = 90, t = 24 (80 p 160)			0	0	(93)
He	0.074	0	1	0	0	(68)
Hg	0.74	400	1	3	8	(10)
N	0.555	0	1	5; 8	5	(5, 49)
	0.606	0	1	2	6	(108)
	0.581	0	1	Radio		(151)
	0.79	− 75	1	1	6	(153)
	1.90	−189	1	1	6	(153)
O	0.507	0	1	5	5	(5)
	0.510	0	1	8	5	(49)
	0.547	0	1	2	6	(108)
	0.518	0	1	Radio		(151)
	c = 173, t = 13.5 (35 p 110)			0	0	(93)
H_2O	*See* Table 4					
HCl	2.6	100	1	Audio		(5)
	7.6	− 75	1	Radio		(151)
	4.60	0	1	Radio		(151)
	2.50	100	1	Radio		(151)
	1.62	200	1	Radio		(151)
	1.40	300	1	Radio		(151)
HBr	3.44	− 50	1	Radio		(151)
	3.13	0	1	Radio		(151)
	2.62	100	1	Radio		(151)
	2.30	200	1	Radio		(151)
	2.12	300	1	Radio		(151)
HI	2.38	− 25	1	Radio		(151)
	2.34	0	1	Radio		(151)
	2.20	100	1	Radio		(151)
	2.15	200	1	Radio		(151)
	2.16	300	1	Radio		(151)
	2.18	350	1	Radio		(151)
SO_2	9.5	0	1	0	0	(75)
	9.0*	0	1	0	0	(135)
	9.3†	0	1	Audio		(5)
	9.5	0	1	1	6	(153)
	5.3	100	1	1	6	(153)
	3.9	175	1	1	6	(153)

* α = −4.7 (10° t 60°) (135).

† α = −6.32, β = 18.7 (10° t 100°) audio (5).

TABLE 1.—(*Continued*)

	$\Delta_{t,p}$	t	p	A	n	Lit.
H_2S	4.0‡	0	1	1	6	(15)
	ϵ = 2.0§	10	*v.p.*	Audio		(38)
N_2O	0.99	0	1	0	0	(12)
	1.16	0	1	0	0	(75)
	1.13	0	1	2	6	(108)
	10	15	10	0	0	(82)
	25	15	20	0	0	(82)
	46	15	30	0	0	(82)
	72	15	40	0	0	(82)
			mm	% NO_2		
$N_2O_4 + NO_2$	2.3	42.5	747	31		(5)
	2.4	49.7	746	39		(5)
	1.4	63.1	747	55		(5)
	1.4	68.7	741	63		(5)
	1.0	90.5	741	84		(5)
	1.3	92.1	747	85		(5)
			p	A	n	
NH_3	8.37¶	0	1	Audio		(5)
	9.2	− 30	1	1	6	(153)
	7.2	0	1	1	6	(153)
	4.0	100	1	1	6	(153)
	2.7	185	1	1	6	(153)
CO	0.695	0	1	0	0	(12, 15, 75)
	0.70	0	1	5	1	(104)
	2.63	−189	1	Radio		(106)
CO_2	0.98**	0	1	≤2	6	(5, 12, 49, 75, 104, 108, 134, 135)
	0.98††	0	1	1	6	(153)
	1.41	− 73	1	Radio		(106)
	50	0	*v.p.*	0	0	(135)
	c = 332, t = 13.5 (10 p 50)			0	0	(93)
	8	15	10	0	0	(82)
	19	15	20	0	0	(82)
	37	15	30	0	0	(82)
	62	15	40	0	0	(82)
	See also Fig. 2					
CS_2	2.9	0	1	0	0	(75)
	3.2‡‡	0	1	0	0	(5)
Air	*See* Table 3					

‡ $\alpha = -5$ (0° t 100°). § *See* Fig. 1.
¶ $\alpha = -7.75$, $\beta = 31$ (18° t 108°) audio (5).
** $\alpha = (3.71 + 0.05p)$ (9° t 66°) (1 p 5) (134, 135).
†† $\alpha = -4.3$, $\beta = 11$ ($-75°$ t 200°) (153).
‡‡ $\alpha = -3$ 7 (85° t 130°) (5).

TABLE 2.—DIELECTRIC CONSTANT (ϵ) OF PURE INORGANIC SOLIDS AND LIQUIDS AND ITS VARIATION WITH TEMPERATURE (t), PRESSURE (p), AND FREQUENCY (ν)

For SiO_2, *v.* p. 341; for single crystals, *v.* p. 98

From certain solids it is difficult, or even impossible, to prepare plates which are sufficiently homogeneous to be used for a direct determination of the dielectric constant (ϵ) of the material. In such case, it is customary to deduce ϵ from the effective dielectric constant (ϵ') of a dry plate formed by compressing the powdered substance, or from the effective constant (ϵ_1) of such a plate when saturated with a liquid (dielectric constant = ϵ'') which does not dissolve the powder. For such deduction, one or another of the following equations is generally used:

(1) $(\epsilon - 1)/d = (\epsilon' - 1)/d'$; (2) $(\epsilon - 1)/d(\epsilon + 2) = (\epsilon' - 1)/d' \times (\epsilon' + 2)$; (3) $(\epsilon - 1)/d(\epsilon + n) = (\epsilon' - 1)/d'(\epsilon' + n)$; (4) $(\epsilon - \epsilon'')/d = (\epsilon_1 - \epsilon'')/d'$. Here d = density of the substance, d' = density of the dry plate, and n is Wiener's number (152).

All liquids are under the pressure of saturated vapor unless contrary is indicated in first column. In column (2), l = liquid, s = solid, ls = intermediate between liquid and solid, P indicates ϵ was deduced from effective constant of a plate of compressed powder, its subscript indicates equation used.

$$\epsilon_t = \epsilon_{t_0} + \alpha(t - t_0)(10)^{-3} + \beta(t - t_0)^2(10)^{-6}; \epsilon_p = \epsilon_0(1 + ap(10)^{-4} + bp^2(10)^{-8}); \nu = A \times 10^n$$

Unit of ϵ = 1 cgse unit, of p = 1 atmosphere, of ν = 1 cycle/sec of t = 1°C

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
A-Table.—The A-Arrangement						
Br	l	3.2	23	1	8	(114)
	l	3.1	t_R	1	8	(117)
C (Diamond)	s	16.5	t_R	Audio		(103)
	s	5.5	t_R	1	8	(117)
Cl	l	1.97*	0	0	0	(82)
	l	2.0†	0	Audio		(38)
	l	1.9	14	2	6	(26)
H (p = 1)	l	1.22‡	−253	1	5	(16)
(p = 1)	l	1.225§	−253	6	5	(148)
	l	1.253‖	−259	1	5	(145)
	s	1.21¶	−259.9	6	5	(148)
	s	1.21	−259.1	1	5	(145)
He (p = 1)	l	1.048	−268.9	6	5	(148)
	l	1.058	−270.8	6	5	(146)
	l	1.056	−271.3	6	5	(146)
I	s	10	23	1	8	(114)
	s	4	t_R	1	8	(117)
O (p = 1)	l	1.465	−182	0	0	(63)
(p = 1)	l	1.493	−182	0	0	(44)
	l	1.46	−182	1	5	(16)
	l	1.51**	−203	1	5	(16, 146)
P (p = 1)	l	3.85	20; 45	1	8	(115)
	s	4.1	20	1	8	(115)
(Yellow)	s	3.6	t_R	1	8	(117)
S‖‖ (p = 1)	l	3.42	400	Audio		(103)
(p = 1)	ls	3.98	115	Audio		(103)
	s	4.22††	t_R	Audio		(103)
	s	4.0	t_R	0	0	(53)
	s	4.01‡‡	0	0	0	(118)
	s	4.38	t_R	0	0	(130)
	s	4.05††	t_R	5.0	1	(41)
	s	3.80§§	t_R	5.0	1	(41)
	s	4.03	t_R	8.0	1	(130)
	s	4.03	t_R	9.3	1	(42)
	s	4.2	16	1	3	(46)
	P_2	4.7	17	1	6	(74)
	s	3.24¶¶	25	3.8	10	(79)
	s	4.03¶¶	25	5.0	10	(79)
	s	4.00¶¶	25	7.5	10	(79)
Se	s	6.13***	20	5.0	1	(138)
	s	7.44	t_R	Audio		(103)
	s	6.14***	20	2.4	7	(138)
	s	6.6	t_R	1	8	(117)

* $\alpha = -3.0$ ($-70°$ t 10°) (82).
† $\alpha = -3.5$ (0° t 140°) (38).
‡ $\alpha = -2.8$ ($-259°$ t t_0) (16).
§ $\alpha = -3.2$ ($-259°$ t t_0) (148).
‖ $\alpha = -3$ (t_0 t − 253°) (145).
¶ $\alpha = 45$ (t_0 t −259.1°) (148).
** $\alpha = -2.2$ (t_0 t − 183°) (16, 146).
†† Freshly crystallized.
‡‡ $\alpha = +1$; ($-140°$ t 80°) (118).
§§ Several months old.
‖‖ Power factor for solid S = 0.03 % at 16°C, $\nu = 10^3$ (46); =0.6 % at t_R, $\nu = 10^6$ (57).
¶¶ From deviation of waves by a prism.
*** Vitreous; in dark.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
$\mathfrak{B}$-Table.—Standard Arrangement; *v.* Vol. III, p. viii						
H_2O	*See* Table 4					
HCl	*l*	4.60	27.7	4	8	(113)
	l	8.85	− 90	4	8	(113)
HBr	*l*	3.82	24.7	4	8	(113)
	l	6.29	− 80	4	8	(113)
HI	*l*	2.9	21.7	4	8	(113)
	l	2.88	− 50	4	8	(113)
	s	3.95	− 70	4	8	(110)
SO_2	*l*	15.6*	0	Audio		(37)
(p = 1)	*l*	13.8	15	2	8	(87)
	l	12.4	22	1	8	(114)
SO_3	*l*	3.56	21	1	8	(114)
	s	3.64	19	1	8	(114)
H_2S†	*l*	5.75‡	10	Audio		(38)
H_2SO_4 (p = 1)	*l*	>84§	20	1	8	(140)
	s	3.8‖	−180	1.2	2	(28)
S_2Cl_2	*l*	4.8	22	1	8	(114)
$SOCl_2$	*l*	9.05	22	1	8	(114)
SO_2Cl_2	*l*	9.15	22	1	8	(114)
(p = 1)	*l*	8.5	22	1	8	(140)
N_2O	*l*	1.607¶	0	0	0	(82)
(p = 1)	*l*	1.933	− 90			(63)
N_2O_4	*l*	2.56	15	1	8	(115)
	s	2.6	− 40	1	8	(115)
NH_3	*l*	14.9	24.5	4	8	(96)
	l	15.5	20.5	4	8	(96)
	l	16.2	14	2	6	(26)
(p = 1)	*l*	22	− 34	4	8	(52)
	l	25.4	− 77	4	8	(96)
	s	4.01	− 90	4	8	(96)
HNO_3	*s*	2.4	**	1.2	2	(28)
NH_4Cl	P_2	7.0	t_R	1	6	(72)
NH_4Br	P_2	7.1	t_R	1	6	(72)
$(NH_4)_2SO_4$	P_2	3.3	17	1	6	(74)
PH_3	*l*	2.71	− 25	4	8	(96)
	l	2.55	− 60	4	8	(96)
PCl_3	*l*	3.72	18	1	8	(115)
	l	3.4	22	1	8	(114)
$POCl_3$	*l*	14	22	1	8	(114)
PBr_3	*l*	3.88	18	1	8	(115)
PI_3	*l*	4.12	65	1	8	(115)
	s	3.66	20	1	8	(115)
AsH_3	*l*	2.05	15	4	8	(116)
	l	2.74	− 50	4	8	(116)
$AsCl_3$	*l*	12.35	21	1	8	(114)
(p = 1)	*l*	12.8	20	1	8	(140)
	l	12.6	17	1	8	(115)
	s	3.6	− 50	1	8	(115)
$AsBr_3$	*l*	8.83	35	1	8	(115)
(p = 1)	*l*	9.3	35	1	8	(140)
	s	3.33	20	1	8	(115)
	s	3.4	20	1	8	(140)
AsI_3	*l*	7.0	150	1	8	(115)
	s	5.4	18	1	8	(115)
SbH	*l*	2.58	− 50	4	8	(96)
	l	2.93	− 80	4	8	(96)
$SbCl_3$	*l*	33.2	75	1	8	(114)
	s	5.34	18	1	8	(114)

* $\alpha = -78$ ($0° < t < 150°$) (37).
† *See* Fig. 1.
‡ $\alpha = -23$, $\beta = -25$ ($t_0 < t < 80°$) (38).
§ d = 1.85 g/cm³.
‖ $\alpha = +9$ ($-185° < t < -120°$).
¶ $\alpha = -6.1$ ($-6° < t < 14°$) (82).
** −185° to −110°.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
$SbCl_5$	*l*	3.78	21.5	1	8	(114)
$SbBr_3$	*l*	20.9	100	1	8	(115)
	s	5.05	20	1	8	(115)
SbI_3	*l*	13.9	175	1	8	(115)
	s	9.1	20	1	8	(115)
CO_2*	*l*	1.585†	0	0	0	(82, 135)
CS_2 (p = 1)	*l*	2.58	46	Audio		(54)
(p = 1)	*l*	2.6	25	Audio		(54)
(p = 1)	*l*	2.64	20	1.2	2	(27, 45)
(p = 1)	*l*	2.647‡	20	8.5	5	(78)
(p = 1)	*l*	2.638§	19	Audio		(95)
(p = 1)	*l*	2.64	17	4	8	(31)
(p = 1)	*l*	2.61	15	1.5	8	(59)
(p = 1)	*l*	2.644‖	13	7	2	(139)
(p = 1)	*l*	2.676¶	0	Audio		(125)
(p = 1)	*l*	2.68**	0	5	5	(71)
(p = 1)	*l*	2.638††	0	Radio		(105)
(p = 1)	*l*	2.631‡‡	10	Radio		(55)
(p = 1)	*l*	2.64	− 75	1.2	2	(27, 45)
(p = 1)	*ls*	2.93	− 95	5	5	(71)
(p = 1)	*ls*	2.87	−100	5	5	(71)
(p = 1)	*ls*	2.83	−105	5	5	(71)
(p = 1)	*ls*	2.81	−110	5	5	(71)
	s	2.78§§	−180	5	5	(71)
	s	2.24	−185	1.2	2	(27, 45)
SiO_2	*See* p. 341					
$SiCl_4$	*l*	2.4	16	1	8	(115)
$SnCl_4$	*l*	3.2	22	1	8	(114)
PbO	P_4	25.9	15	1	8	(131)
PbF_2	P_1	3.6	t_R	1	6	(81)
$PbCl_2$	P_1	4.2	t_R	1	6	(81)
	P_2	6.0	17	1	6	(74)
$PbBr_2$	P_1	4.9	t_R	1	6	(81)
PbI_2	P_1	2.4	t_R	1	6	(81)
PbS	P_4	17.9	15	1	8	(131)
$PbSO_4$	P_2	14.3	17	1	6	(74)
$Pb(NO_3)_2$	P_3	37.7	18	6.3	7	(7, 67)
$Pb(CHO_2)_2$	P_2	2.6	17	1	6	(74)
$PbCO_3$	P_4	18.6	15	1	8	(131)
TlCl	P_2	46.9	t_R	1	6	(72)
TlBr	P_2	53.8	t_R	1	6	(72)
Hg_2Cl_2	*s*	9.4	t_R	1	6	(72)
$HgCl_2$	P_2	3.2	17	1	6	(74)
$Hg(CN)_2$	P_2	4.8	17	1	6	(74)
CuO	P_4	18.1	15	1	8	(131)
$CuCl_2.2H_2O$	P_3	7.6	20	6.3	7	(7, 67)
$CuSO_4$	P_3	10.3	18	6.3	7	(7, 67)
$CuSO_4.5H_2O$	P_3	7.8	18	6.3	7	(7, 67)
	P_4	5.5	15	1	8	(131)
AgCl	*s*	11.2	t_R	1	6	(72)
AgBr	*s*	12.2	t_R	1	6	(72)
AgCN	P_2	5.6	t_R	1	6	(72)
FeO	P_4	14.2	15	1	8	(131)
$FeF_3.3H_2O$	P_3	7.3	20	6.3	7	(7, 67)
$CrF_3.4H_2O$	P_3	6.8	21	6.3	7	(7, 67)

* *See* Fig. 2.
† $\alpha = -3.9$ ($-7.5° < t < 17.5°$) (82); $\alpha = -2.7$, $\beta = -110$ ($-5° < t < 30°$) (135).
‡ a = 0.723, b = − 0.722 (1 < p < 3000) (78).
§ a = 0.726, b = − 1.33 (1 < p < 500) (95).
‖ a = 0.757, b = − 3.71 (1 < p < 130) (139).
¶ $\alpha = -2.61$, $\beta = -1.24$ ($20° < t < 180°$) (125).
** $\alpha = -2.8$ ($-90° < t < 200°$) (71).
†† $\alpha = -2.6$ ($-5° < t < 37°$) (105).
‡‡ $\alpha = -1.9$ ($10° < t < 40°$) (55).
§§ $\alpha = +0.3$ ($-186° < t < -110°$) (71).

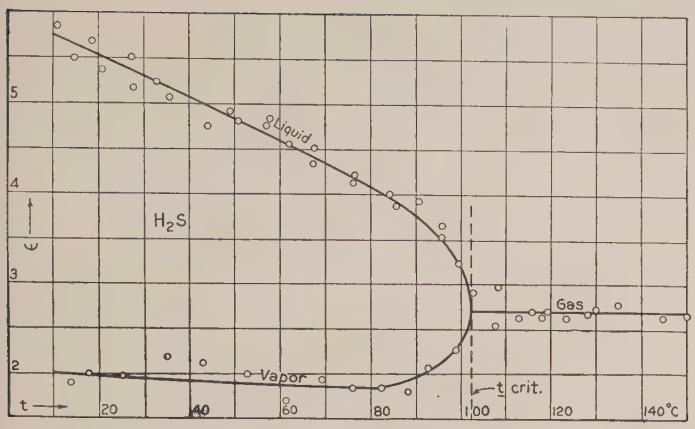

FIG. 1.—Dielectric constant (ϵ) of H_2S (38) at audio frequency. Below the critical temperature, pressure (p) is that of the saturated vapor; above the critical temperature, p = critical pressure.

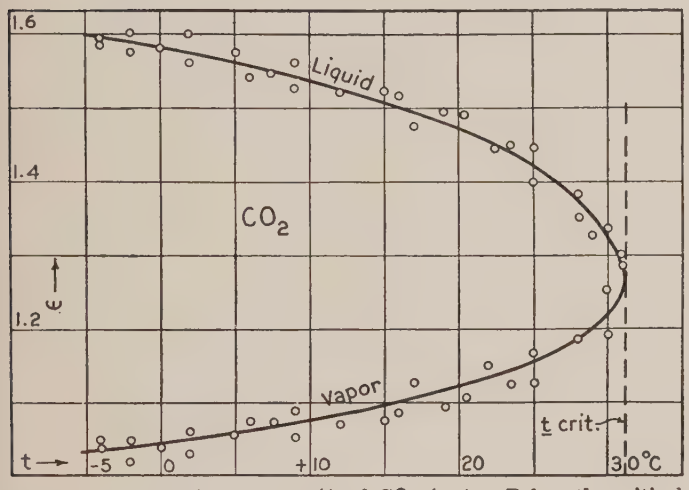

FIG. 2.—Dielectric constant (ϵ) of CO_2 (135). Below the critical temperature, pressure (p) is that of the saturated vapor; above the critical temperature, p = critical pressure; $\nu = 4 \times 10^8$ cycle/sec.

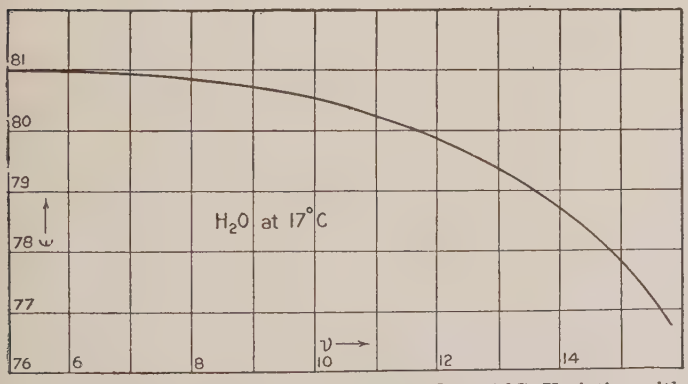

FIG. 3.—Dielectric constant (ϵ) of liquid H_2O at 17°C: Variation with frequency (ν) (25, 26).

Unit of $\nu = 10^8$ cycle/sec; of $\epsilon = 1$ cgse.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
$CrO_2.Cl_2$ (p = 1)	l	2.6	20	1	8	(140)
VCl_4	l	3.05	25	4	8	(84)
$VOCl_3$	l	3.4*	0	4	8	(84)
$VOBr_3$	l	3.85†	0	4	8	(84)
CaF_2	s	7.36	t_R	Audio		(103)
$CaSO_4.2H_2O$	s	5.61	15	1	6	(131)
$CaSO_4.2H_2O$	s	5.66	t_R	Audio		(103)
$CaCO_3$	s	6.14	t_R	1	6	(131)
BaF_2	P	2.3‡	18	6.3	7	(7)
$BaCl_2$	P_3	11.4	19	6.3	7	(7, 67)
$BaCl_2.2H_2O$	P_3	9.4	19	6.3	7	(7, 67)
$BaBr_2.2H_2O$	P_3	10.9	19	6.3	7	(7, 67)
$Ba(BrO_3)_2.H_2O$	P_3	8.0	20	6.3	7	(7, 67)
$Ba(IO_3)_2.H_2O$	P_3	12.9	18	6.3	7	(7, 67)
$BaSO_4$	P_4	11.4	15	1	8	(131)
	P	3.3§	18	6.3	7	(7)
$Ba(NO_3)_2$	P_3	5.9	18	6.3	7	(7, 67)
	P_4	9.15	15	1	8	(131)
$Ba(CNS)_2.3H_2O$	P_3	12.8		6.3	7	(7, 67)
$BaCrO_4$	P	4.25‖	18	6.3	7	(7)
NaF	P_3	3.9	19	6.3	7	(7, 67)
NaCl	s	6.12	t_R	Audio		(103)
	s	5.81	t_R	1	6	(131)
	s	9.3	t_R	4	9	(80)
	P_3	6.3	19	6.3	7	(7, 67)
$NaClO_4$	P_3	5.4	19	6.3	7	(7, 67)
$NaBrO_3$	P_3	7.7	19	6.3	7	(7, 67)
$NaNO_3$	s	5.2	t_R	0	0	(4)
Na_2CO_3	P_3	8.4	20	6.3	7	(7, 67)
$Na_2CO_3.10H_2O$	P_3	5.3	20	6.3	7	(7, 67)
$KF.2H_2O$	P_3	5.9	20	6.3	7	(7, 67)
KCl	s	5.03	t_R	Audio		(103)
	P_3	4.9	19	6.3	7	(7, 67)
	P_2	2.4	17	1	6	(74)
$KClO_3$	P_3	5.1	18	6.3	7	(7, 67)
	P_4	6.2	15	1	8	(131)
KBr	s	4.6	t_R	1	6	(72)
	P_3	4.7	18	6.3	7	(7, 67)
KI	P_3	5.6	18	6.3	7	(7, 67)
	P_2	5.2	t_R	1	6	(72)
K_2SO_4	P_3	5.9	19	6.3	7	(7, 67)
	P_4	6.4	15	1	8	(131)
KNO_3	s	2.7	t_R	0	0	(4)
	P_3	5.0	19	6.3	7	(7, 67)
K_2CO_3	P_4	5.6	15	1	8	(131)
$K_2CO_3.2H_2O$	P_3	6.6	20	6.3	7	(7, 67)
K_2CrO_4	P_3	7.3	19	6.3	7	(7, 67)
$K_2Al_2(SO_4)_4.24H_2O$	P_2	3.8	17	1	6	(74)

* $\alpha = -0.4$ ($-70° < t < 26°$) (84).
† $\alpha = -8$ ($-70° < t < 30°$) (84).
‡ For plate, $d' = 1.6$ g/cm³, value not reduced.
§ For plate, $d' = 1.9$ g/cm³, value not reduced.
‖ For plate, $d' = 1.85$ g/cm³, value not reduced.

TABLE 3.—DIELECTRIC CONSTANT OF AIR

For gaseous air, $\epsilon = \dfrac{1 + 2c_1d_1}{1 - c_1d_1} = 1 + 3c_1d_1 + 3c_1^2d_1^2 + \ldots = 1 + 3c_1d_1(1 + c_1d_1) + \ldots$; $d_1 = p/(1 + 0.003665t)$ if unit of $p = 1$ atmosphere, of $t = 1°C$. ϵ is independent of the frequency. If we write $c_1 = c \times 10^{-6}$, $c = 195$; tested and found

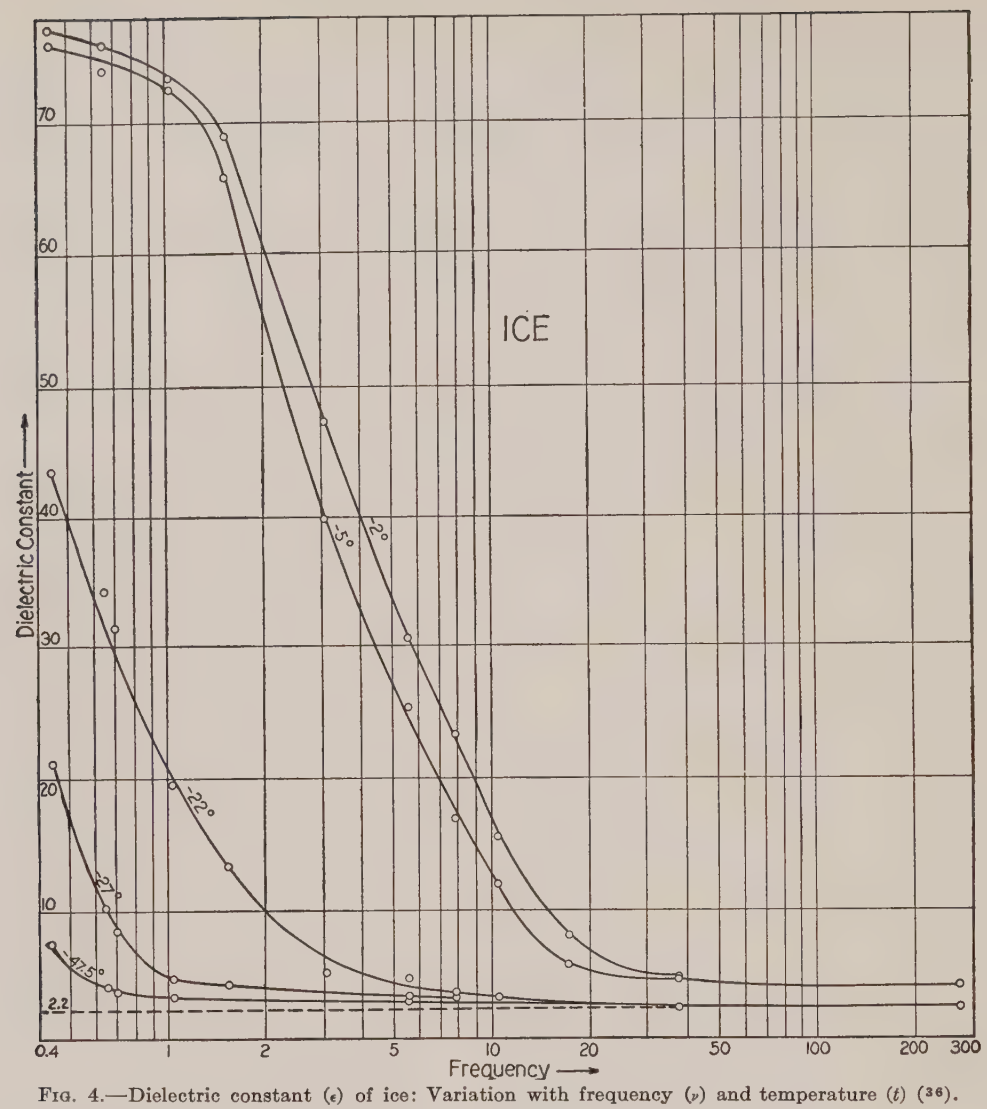

FIG. 4.—Dielectric constant (ϵ) of ice: Variation with frequency (ν) and temperature (t) [36].
Unit of ν = 1 kilocycle/sec; of ϵ = 1 cgse; t = °C.

constant for (0 p 175); (0° t 70°) [9, 19, 49, 51, 75, 92, 94, 104, 126, 127, 135, 139]; at very low temperatures, c is a few per cent greater than 195; at −185.5°C, $\epsilon - 1 = 0.001890/p$. ν = frequency, cycle/sec. Unit of ϵ = 1 cgse; of p = 1 atm.; of t = 1°C.

Gaseous, p = 1			Liquid, p = 1			
t	ϵ	Lit.	t	ϵ	ν	Lit.
0	1.000585		−185	1.432	(?)	[103]
−185.5	1.00189	[106]	−185	2.28	7.5×10^9	[88]

TABLE 4.—DIELECTRIC CONSTANT (ϵ) OF H_2O; STEAM, WATER, AND ICE

Unit of ϵ = 1 cgse unit, of p = 1 atmosphere, of ν = 1 cycle/sec; of t = 1°C.

Steam, p = 1, (140° t 150°): $\epsilon = 1.00785 - 0.00016\ (t - 140°)$ [5]. If (0 p' 40) (40° t 165°), $\epsilon = 1 + [9.3 - 0.026(t - 40)]p' \times 10^{-6}$, where unit of p' = 1 mm of Hg [152].

Water, p = 1, (0° t 100°) (0 ν 10^8): $\epsilon = 80 - 0.4\ (t - 20°)$, [18, 23, 24, 28, 50, 65, 69, 73, 74, 86, 90, 91, 105, 107, 109, 110, 121, 122, 128, 131, 133, 150]. For $\nu > 10^8$, the value of ϵ is uncertain; two observers [25, 111], using standing waves along wires, find ϵ decreases as ν increases (*see* Fig. 3); another [79], from measurements of refraction, concludes that the reverse is true.

At 16.3°C, $\nu = 6 \times 10^7$ (7 p 200), $\epsilon = 81.5 + 0.0046p$ [39].

Ice, at −5°C (10^7 ν 10^9), $\epsilon = -0.08 + 0.34 \log_{10} \nu$ [58]. For variation with ν and t, *see* Fig. 4. Other determinations are tabulated below.

t	$\epsilon_{t,\nu}$	t	$\epsilon_{t,\nu}$	t	$\epsilon_{t,\nu}$
ν = 50 [129]		ν = 120* [27, 45]		ν = 320 [28]	
− 2	94	− 80	31.5	− 7	51
− 10	95.2	− 90	20.2	− 47	3.6
− 18	96.5	−100	14.5	Audio [1]	
−182	3	−110	8.6	− 80	3.8
ν = 120* [27, 45]		−120	6.1	$\nu = 5 \times 10^6$ [2]	
− 20	59.5	−130	4.7	0 to −24	3.8
− 30	59.0	−140	3.5	$\nu = 10^7$ [131]	
− 40	58.5	−150	2.7	− 2	3.4
− 50	56.0	−165	2.43	− 5	2.3†
− 60	49.5	−185	2.43	− 5	2.8
− 70	41.5	−185	2.83	$\nu = 10^8$ [11]	
				−190	1.8

* Condenser charged and discharged by commutator, 120 charges per sec; *see also* Fig. 5. † From [58].

TABLE 5.—EFFECT OF ILLUMINATION UPON DIELECTRIC CONSTANT (56)

For a phosphorescent ZnS containing a trace of Cu, $\epsilon_l - \epsilon_d = B\epsilon_d(1 - e^{-aJ})$, where ϵ_l, ϵ_d = dielectric constant in the light, in the dark, and J = irradiation of the material. B and a vary with the wave-length (λ) of the light. For room temperature and $\nu = 3 \times 10^6$ cycle/sec, the following values were found. Unit of λ = $1m\mu = 10$ Å; of $J = 10^{-12}$ watt cm^{-2}.

λ	313	365	405	435
B	0.006	0.035	0.042	0.033
a	13.2	9.1	5.0	12.4

TABLE 6.—RELATIVE DIELECTRIC STRENGTHS OF PURE INORGANIC GASES AT 25°C AND 1 ATMOSPHERE (6, 13, 64, 70, 76, 85, 97, 120, 132, 147, 149)

For other pressures, *v.* (61, 62, 97, 141, 147) or use Paschen's law (*v.* Table 7). Values are not affected by the electrode material except in the case of gases of low ionization potential at low pressure, but are affected by the condition of the electrode surface (32, 154). For a mixture of two gases which do not react chemically (64, 70) $(p_1 + p_2)V = p_1V_1 + p_2V_2$ where p_1 and p_2 are the partial pressures of the two constituents of the mixture, and V_1 and V_2 are the sparking potentials for the pure constituents at 25°C and 1 atmosphere.

The presence of an ionizing radiation does not appreciably lower the electric strength of a gas, but makes the individual observations more concordant by eliminating the variable, temporary excess in voltage, which otherwise occurs (64, 89, 141, 158). For bibliography and discussion of data pertaining to the electrical breakdown of gases, *see* (120, 156).

V/V_a = potential difference at which spark passes in gas *divided by* potential difference at which spark passes in air, the temperature (25°C), pressure (= 1 atm), terminals, and gap-length being the same for each. Accuracy, *ca.* 10%.

Gas	Cl	H	N	O	SO_2	H_2S	NH_3	CO_2
V/V_a	0.85	0.65	1.15	0.85	0.30	0.90	1.00	0.95

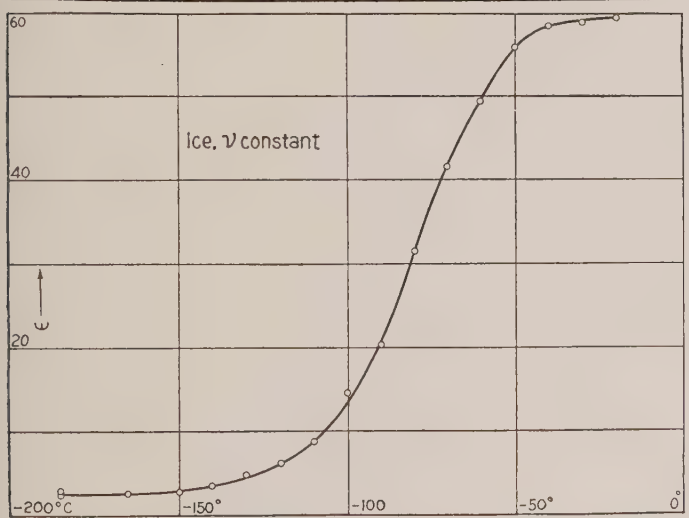

FIG. 5.—Dielectric constant (ϵ) of ice: Variation with temperature, ν is constant at 120 charges (and discharges) per second (27, 45).

TABLE 7.—DIELECTRIC STRENGTH OF AIR: SPHERICAL ELECTRODES, 25°C AND 1 ATMOSPHERE

The tabulated data apply to gaps having the following characteristics: The electrodes are two spheres of the same diameter; variations in diameter should not exceed 0.1% and the curvature should nowhere differ from that of a true sphere by more than 1%. The spheres must be highly polished if the frequency of the emf is very high (*e.g.*, 40 000 cycle per sec); at commercial frequencies and for D.C. potential the degree of polish is much less important. Considerable deviation in successive breakdown values may occur if the sparking surfaces are not properly cleaned (154, 158). The diameter of the shanks supporting the spheres should not exceed 0.2 the diameter of the spheres, and if they pass through metal collars, the collars should be small and not closer to the gap than the length (l) of the latter. Each sphere should be at least $2l$ distant from all surrounding materials other than air.

For other temperatures and pressures, multiply the tabular values of V by the factor f (or, less accurately, by c); $c = 298p/(273 + t)A_n$, $f = \sqrt{c}(\sqrt{cr} + \delta)/\sqrt{r} + \delta$, where r = radius of the electrode, $\delta = 0.54$ cm, p = pressure, A_n = pressure of one normal atmosphere. Paschen's law (147), V is a function of (dl), holds throughout the range within which air is essentially an ideal gas (61); *cf.* (20, 21, 35, 60, 64, 141). Values of V are independent of the humidity of the air and of the electrode material (32, 98, 99, 124, 144), d = density, D = diameter of spheres, G = one sphere grounded, connected to earth, I = both spheres insulated from earth, l = shortest distance between surfaces of spheres, u = greatest uncertainty in the data, it is probably several times greater than actual error, V_m = maximum value of A.C. voltage. Unit of D and of l = 1 cm; of V_m = 1 kilovolt = 10^{11} cgsm unit = 3.335 cgse unit.

D	0.25	0.50	1.0	D	2.0	2.5	3.0	4.0
l	V_m			l	V_m			
0.01	1.08	1.01	0.86	0.10	4.62		4.50	
.02	1.59	1.51	1.49	.20	7.84		7.80	8.4
.03	2.06	2.00	1.94	.30	10.9		11.0	11.4
.05	2.92	2.83	2.78	.40	13.9		13.8	14.4
.08	4.00	3.92	3.92	.50	16.9	18.3		17.4
.10	4.73	4.67	4.67	.60	19.7	21.4		20.2
.15	6.60	6.54	6.42	.80	24.9	27.2		25.4
.20	8.34	8.26	8.08	1.0	29.5	32.8		30.0
.30	11.3	11.4	11.3	1.2	33.4	38.3	37.8	34.2
.40	13.7	14.5	14.4	1.4	36.8	43.3	43.5	
.50	15.8	17.3	17.4	1.6	39.7	48.3	49.0	
.60	17.4	19.8	20.4	1.8	41.8	53.1	54.0	
.80	19.2	23.9	25.7	2.0	43.6	57.4	58.8	
1.00	20.5	26.9	29.8	2.5	45.8	66.5	69.3	
1.20	21.7		34.7	3.0	46.5	72.9	78.0	
1.40	22.5		38.3	3.5	48.3	78.0	84.7	
1.60			41.5	4.0	49.2	82.4	90.4	
				4.5	50.0	86.0	92.7	
				5.0	50.5	89.5		
	One sphere grounded in all cases			6.0	51.2	One sphere grounded in all cases		
				8.0	52.4			
u	5 %	5 %	5 %	u	5 %	7 %	7 %	10 %
Lit.	(66, 97)	(66, 97)	(48, 66, 97, 137)	Lit.	(48, 77, 89, 137, 156)	(66, 97)	(6)	(48)

D	5.0		10.0		12.5		15.0	20.0
l	V							
	I	G	I	G	I	G	G	G
0.1			4.46	4.46			4.44	4.39
0.2			7.64	7.64			7.58	7.62
0.3			10.6	10.6	10.8	10.8	10.62	10.52
0.4			13.4	13.4	14.0	14.0	13.44	13.44
0.5	17.1	17.1	16.3	16.3	17.0	17.0	16.30	16.30
0.6	20.2	20.2	19.5	19.1	19.9	19.9	19.07	19.14
0.8	26.3	26.2	25.2	24.6	25.5	25.5	24.5	24.6
1.0	32.0	31.8	30.8	29.8	31.1	31.1	29.9	29.8
1.2	37.6	37.2	36.4	35.1	36.5	36.5	35.1	34.9
1.4	42.8	42.3	41.7	40.2	41.9	41.9	40.1	40.0
1.6	47.9	47.0	47.0	45.3	47.2	47.2	45.0	45.1
1.8	52.8	51.7	52.6	50.2	52.6	52.6	49.9	
2.0	57.4	55.8	57.6		58.0	58.0		
2.5	68.3	65.0	70.0		70.7	70.7		
3.0	77.7	72.0	80.9		83.1	82.8		
3.5	86.1	77.4	93.4		95.2	94.5		
4.0	93.4	81.0	104.5		106.8	105.2		
4.5	100.6	84.2	114.7		117.8	115.6		
5.0	106.0	86.5	125.0		128.5	125.5		
6.0	116.4	88.8	143.5		147.2	143.4		
7.0	126.0	90.0	159.5		167	158		
8.0	134	90.4	173.4		184	171		

TABLE 7.—(*Continued*)

D	5.0		10.0		12.5		15.0	20.0
l	V							
	I	G	I	G	I	G	G	G
9.0	140	90.9	186		200	182		
10.0	145	92	198		213	191		
12.0	155	93	218		238	208		
14.0	162		235		258	220		
16.0	168		248		274	230		
18.0	175		261		288	239		
20.0	180		270		302	246		
25.0	194		288					
30.0	207		294					
35.0	220							
40.0	233							
45.0	248		u = 5 % in all cases					
Lit.	(3, 66, 83, 89, 136, 137, 156)		(77, 136, 156)		(99, 101)		(77, 156)	(77)

D	25		30		50	75	
l	V_m						
	I	G	I	G	G	I	G
0.1			4.36	4.36			
0.2			7.58	7.58			
0.3			10.53	10.53			
0.4			13.44	13.44			
0.5			16.30	16.30			
0.6			19.37	19.08			
0.8			25.1	24.4			
1.0		30.9	30.6	29.6			
1.2			35.9	34.8			
1.4		42.7	40.9	39.8			
1.6			46.1				
1.8			51.1				
2.0		59.6	56.4		56.6		
2.5		73.5	69.2				
3.0		86.7	82.2		84.0		
3.5		99.4	95.2				
4.0	112.0	111.5	108.0		110.8		
4.5	124.1	123.7	120.6				
5.0	136.0	135.0	133.0		137.0		
6.0	160.8	159.6	157.8		162.6		
7.0	181	178	181		188		
8.0	202	198	205		212		
9.0	222	218	227		236		
10.0	241	235	247		259		
12.0	277	268	284		305		
14.0	310	296			347		
16.0	341	320			387		
18.0	369	342			425		
20.0	392	360			456	502	502
25.0	443	392				605	605
30.0	480	417				696	696
35.0	514	441				784	770
40.0	548	460				866	835
45.0						936	887
50.0						1000	940
60.0						1120	1030
70.0						1225	1105
80.0						1303	
90.0	u = 5 % except for D = 75.0, for which 7 %					1376	
Lit.	(22, 99, 101, 156)		(136)		(22, 99, 101, 155)	(102)	

TABLE 8.—DIELECTRIC STRENGTH OF AIR: NEEDLE ELECTRODES, 25°C AND 1 ATMOSPHERE (48, 99, 100, 101, 102, 136, 141, 157)

The tabular data apply to gaps having the following characteristics: The electrodes are new sewing needles, No. 00, supported axially at the ends of linear conductors at least $2l$ long. There must be no other material than air nearer than $2l$ to any portion of the gap. Needles must be replaced after each spark. A needle-gap is not suitable for the measurement of impulsive or high frequency voltage.

For other temperatures and pressures, multiply the tabular values of V by the factor f (or c), *v.* introduction to Table 7. Values of V vary with humidity, and for D.C. differ from V_m of A.C., h = relative humidity, u = greatest uncertainty in the data, it is probably several times greater than actual error, V_e = effective A.C. voltage. Unit of l = 1 cm; of h = 1%; of V, V_e, V_m = 1 kilovolt = 10^{11} cgsm unit = 3.335 cgse unit.

h	0	57	70	75	82.5	l	A.C.	D.C.
l	u = 5%, V_e(60 cycle/sec)						V_m	V
1	8.1	8.1	8.1	8.1	8.1	Humidity is not stated		
2	15.8	15.8	15.8	15.8	15.8			
3	23.1	23.1	23.1	23.1	23.1		(100)	(100)
4	29.5	29.5	29.5	29.5	29.5			
5	34.6	34.6	34.6	34.6	34.6			
6	39.4	39.4	39.4	39.4	39.4	5.1	51.0	52.0
7	43.1	43.2	43.3	43.5	43.7			
8	46.5	46.7	47.3	47.5	47.8	7.6	62.5	63.0
9	49.5	50.1	51.0	51.3	51.6			
10	52.0	53.0	54.3	54.7	55.6			
12	56.9	58.4	61.1	61.6	62.1	10.2	76.5	73.5
14	62.2	64.3	67.0	68.0	69.3	12.7	88.3	82.5
16	67.7	70.6	73.6	74.8	76.5			
18	73.4	75.9	80.1	81.4	83.4	15.3	98.3	90.5
20	79.4	83.4	86.8	88.4	90.7			
25	94.1	99.1	103.3	106.0	108.2	A.C. is 60 cycle/sec		
30	109.4	115.8	121.0	123.6	126.4			
40	140.0	148.6	153.3	157.0	162.1			
50				192				
75				280				
280				1040				

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abegg, *8*, **62**: 249; 97. (2) Abegg, *8*, **65**: 229; 98. (3) Algermissen, *8*, **19**: 1007; 06. (4) Arons, *8*, **53**: 95; 94. (5) Bädeker, *7*, **36**: 305; 01. (6) Baille, *6*, **29**: 181; 83. (7) Baumann, *Diss.*, Rostock, 1914. (8) Beaulard, *34*, **144**: 904; 07. (9) Bedeau, *34*, **174**: 380; 22.

(10) Bedeau, *34*, **175**: 147; 22. (11) Behn and Kiebitz, *in Boltzmann Festschrift*, **1904**: 610. Leipzig, Barth. (12) Boltzmann, *8*, **155**: 403; 75. (13) Bouty, *16*, **16**: 5; 21. (14) Bramley, *2*, **25**: 858; 25. (15) Braunmühl, *63*, **28**: 141; 27. (16) Breit and Onnes, *168*, **No. 171a**. *64P*, **27**: 617; 24. (17) Bryan, *2*, **22**: 399; 23. (18) Carman, *2*, **24**: 396; 24. (19) Carman and Hubbard, *2*, **29**: 299; 27.

(20) Cassuto and Occhialini, *59*, **14**: 330; 07. (21) Ceruti, *72*, **42**: 476; 09. (22) Chubb and Fortescue, *129*, **32**: 739; 13. (23) Cohn and Zeeman, *64V*, **4**: 108; 96. (24) Cole, *8*, **57**: 290; 96. (25) Colley, *63*, **10**: 329, 471; 09. (26) Coolidge, *8*, **69**: 125; 99. (27) Dewar and Fleming, *5*, **61**: 2, 358; 97. (28) Dewar and Fleming, *5*, **62**: 250; 98. (29) Drude, *8*, **58**: 1; 96.

(30) Drude, *8*, **59**: 17; 96. (31) Drude, *7*, **23**: 267; 97. (32) Dubois, *34*, **175**: 947; 22. (33) Ebert and Keesom, *64P*, **29**: 1188; 26. (34) Eckert, *88*, **15**: 307; 13. (35) Ekern, *116*, **18**: 392; 04. (36) Errera, *51*, **5**: 304; 24. (37) Eversheim, *8*, **8**: 539; 02. (38) Eversheim, *8*, **13**: 492; 04. (39) Falckenberg, *8*, **61**: 145; 20.

(40) Faraday, *Experimental researches in electricity*, I. London, Bernard Quaritch, 1839. (41) Fellinger, *8*, **7**: 333; 02. (42) Ficker, *8*, **31**: 365; 10. (43) Fischer, *535*, **2**: 294; 04. (44) Fleming and Dewar, *5*, **60**: 358; 97. (45) Fleming and Dewar, *5*, **61**: 316; 97. (46) Fleming and Dyke, *121*, **69**: 10; 12. (47) Franke, *8*, **50**: 163; 93. (48) Freyberg, *8*, **38**: 231; 89. (49) Fritts, *2*, **21**: 198; 23.

(50) Fürth, *63*, **25**: 676; 24. (51) Gill, *540*, **2**: 450; 21. (52) Goodwin and Thompson, *2*, **8**: 38; 99. (53) Graetz and Fomm, *8*, **54**: 626; 95. (54) Grimm and Patrick, *1*, **45**: 2794; 23. (55) Grützmacher, *96*, **28**: 342; 24. (56) Gudden and Pohl, *96*, **1**: 365; 20. (57) Guthrie, *529*, **12**: 841; 24. (58) Gutton *34*, **130**: 1119; 00. (59) Gutton, *34*, **158**: 621; 14.

(60) Guye and Guye, *149*, **20**: 5, 111; 05. (61) Guye and Weigle, *149*, **5**: 19, 85, 197; 23. (62) Hammershaimb and Mercier, *149*, **3**: 356, 488; 21. (63) Hasenoehrl, *168*, **No. 52**. *64V*, **8**: 137; 00. (64) Hayashi, *8*, **45**: 431; 14. (65) Heerwagen, *8*, **49**: 272; 93. (66) Heydweiller, *8*, **48**: 213; 93. (67) Heydweiller, *96*, **3**: 308; 20. (68) Hochheim, *88*, **10**: 446; 08. (69) Holborn, *96*, **6**: 328; 21.

(70) Holst and Koopmans, *64P*, **20**: 1025; 18. (71) Isnardi, *96*, **9**: 153; 22. (72) Jaeger, *8*, **53**: 409; 17. (73) Jezewski, *51*, **3**: 293; 22. (74) Joachim, *8*, **60**: 570; 19. (75) Klemenčič, *75*, **91 II**: 712; 85. *428*, **21**: 571; 85. (76) Klemm, *125*, **12**: 553; 23. (77) Kowalski and Rappel, *3*, **18**: 699; 09. (78) Kyropoulos, *96*, **40**: 507, 618; 26. (79) Lampa, *75*, **105 IIa**: 587, 1049; 96.

(80) von Lang, *75*, **105 IIa**: 253; 96. (81) Lenert, *88*, **12**: 1051; 10. (82) Linde, *8*, **56**: 546; 95. (83) Lohmann, *8*, **22**: 1008; 07. (84) Loomis and Schlundt,

60, **19**: 734; 15. (85) Macfarlane, *3*, **10**: 389; 80. (86) Mazzotto, *22*, **5 II**: 301; 96. (87) Merczyng, *8*, **34**: 1015; 11. (88) Merczyng, *8*, **37**: 157; 12. (89) Müller, *8*, **28**: 585; 09.
(90) Nernst, *7*, **14**: 622; 94. (91) Niven, *5*, **85**: 139; 11. (92) Occhialini, *59*, **10**: 217; 05. (93) Occhialini, *59*, **7**: 108; 14. (94) Occhialini and Bodareu, *59*, **5**: 15; 13. (95) Ortvay, *8*, **36**: 1; 11. (96) Palmer and Schlundt, *50*, **15**: 381; 11. (97) Paschen, *8*, **37**: 69; 89. (98) Pedersen, *8*, **71**: 317; 23. (99) Peek, *129*, **32**: 812; 13.
(100) Peek, *119*, **35**: 783; 16. (101) Peek, *B7*. (102) Peek, *107*, **78**: 1319; 21. (103) Pirani, *Diss.*, Berlin, 1903. (104) Pohrt, *8*, **42**: 569; 13. (105) Ratz, *7*, **19**: 94; 96. (106) Riegger, *8*, **59**: 753; 19. (107) Röntgen, *8*, **52**: 593; 94. (108) Rohmann, *8*, **34**: 979; 11. (109) Rosa, *3*, **31**: 188; 91.
(110) Rückert, *8*, **55**: 151; 18. (111) Rukop, *8*, **42**: 489; 13. (112) Sauzin, *34*, **171**: 164; 20. (113) Schaefer and Schlundt, *50*, **13**: 669; 09. (114) Schlundt, *50*, **5**: 157, 503; 01. (115) Schlundt, *50*, **8**: 122; 04. (116) Schlundt and Schaefer, *50*, **16**: 253; 12. (117) Schmidt, *8*, **11**: 114; 03. (118) Schmidt, *8*, **44**: 329; 14. (119) Schumann, *125*, **11**: 1; 22.
(120) Schumann, *Elektrische Durchbruchfeldstärke von Gasen*. Berlin, Springer, 1923. (121) Smale, *8*, **57**: 215; 96. (122) Southworth, *2*, **23**: 631; 24.
(123) Stoecker, *96*, **2**: 236; 20. (124) Stoekle, *2*, **19**: 258; 22. (125) Tangl, *8*, **10**: 748; 03. (126) Tangl, *8*, **23**: 559; 07. (127) Tangl, *8*, **26**: 59; 08. (128) Terešin, *8*, **36**: 792; 89. (129) Thomas, *2*, **31**: 278; 10.
(130) Thornton, *3*, **19**: 390; 10. (131) Thwing, *7*, **14**: 286; 94. (132) Tits, *327*, **31**: 144; 07. (133) Turner, *7*, **35**: 385; 00. (134) Verain, *34*, **154**: 345; 12. (135) Verain, *16*, **1**: 255; 14. (136) Villard and Abraham, *34*, **153**: 1200; 11. (137) Voigt, *8*, **12**: 385; 03. (138) Vonwiller and Mason, *5*, **79**: 175; 07. (139) Waibel, *8*, **72**: 161; 23.
(140) Walden, *7*, **46**: 182; 03. (141) Watson, *46*, **43**: 113; 09. (142) Watson, *201*, **17**: 90; 13. (143) Weichmann, *8*, **66**: 501; 22. (144) Weicker, *98*, **55**: 554; 11. (145) Werner and Keesom, *64P*, **29**: 34; 26. *168*, **No. 178a.** (146) Werner and Keesom, *64P*, **29**: 306; 26. *168*, **No. 178c.** *168*, **No. 190a.** (147) Wolf, *8*, **37**: 306; 89. (148) Wolfke and Onnes, *64P*, **27**: 621, 627; 24. *168*, **No. 171b, 171c.** (149) Wright, *4*, **111**: 643; 17.
(150) Yule, *8*, **50**: 742; 93. (151) Zahn, *2*, **24**: 400; 24. (152) Zahn, *2*, **27**: 329; 26. (153) Zahn, *2*, **27**: 455; 26. (154) Carroll and Cozzens, *39*, **47**: 892; 28. (155) Dessauer, *101*, **44**: 1087; 23. (156) Edler, *Elektrotechnik und Maschinenbau*, **43**: 809, 829; 25. (157) Müller, *125*, **13**: 478; 24. (158) Reukema, *129*, **47**: 38; 28.

DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF SINGLE CRYSTALS, MIXTURES AND SOLUTIONS, PURE ORGANIC COMPOUNDS, AND MISCELLANEOUS MATERIALS*

L. Hartshorn, C. C. Harris, J. A. Hey, T. I. Jones, and A. G. Milligan

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Crystals. Hey.
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* Industrial materials (Vol. II) are excluded from this section; for CS_2, *v.* p. 75.

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* Les matières industrielles (Vol. II) sont exclues de cette section; pour CS_2, *v.* p. 75.

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* I materiali industriali (Vol. II) non sono compresi; per CS_2, *v.* p. 75.

SYMBOLS

In addition to the symbols and abbreviations defined in Vol. I, p 16, and those defined where used, the following symbols will be used throughout this section:

Audio	Indicates that the frequency of the field employed in determination of ϵ lies within the range of audition.
k'	Index of absorption; *see* Vol. I, p. 34, "Absorption."
ϵ	Dielectric constant.
ν	Frequency.
∂_t	100 $(\partial\epsilon/\partial t)$ at temperature t.
(10 t 45)	For values of t lying between 10 and 45°C.
3; 8	For the range 3 to 8.
6.76 ± 4	6.76 ± 0.04.
6 76 ± 0.1	6.76 ± 0.10.

Table 1.—Standard Liquids

The substances included in this table are suitable for calibrating apparatus used for measuring dielectric constants. Values given for $\partial\epsilon/\partial t$ are suitable for use over range of frequency indicated, and over ordinary range of temperature, say from 0 to 30°C; for more extreme temperatures, *see* Table 4. Frequency, $\nu = A \times 10^n$. Unit of ϵ = 1 cgse unit; of $\partial\epsilon/\partial t$ = 1 cgse unit per 1°C; of $\nu(= A \times 10^n)$ = 1 cycle/sec.

		$\epsilon_{20}°$	$\partial\epsilon/\partial t$	Range A	Range n	Range A	Range n	Lit.
C_6H_6	Benzene.....	2.283 ±0.002	−0.0019	5	2	5	8	(34, 75, 77, 183, 188)
Probably best. Colley (34) found dispersion in range 5.5 × 10^8 to 6 × 10^8, and observed that in this range value found for ϵ varied greatly with the decrement; *see* Fig. 1.								
$C_6H_4(CH_3)_2$	*m*-Xylene.....	2.374 ±0.002	−0.0019	5	2	4	8	(42, 87, 147, 177, 183)
$(C_2H_5)_2O$	Ethyl ether.....	4.335 ±0.005	−0.019	0	0	4	8	(42, 49, 86, 87, 136, 177, 183)
Changes with time are liable to occur								
$C_6H_5NH_2$	Aniline.....	7.21 ±0.05	−0.025	0	0	4	8	(95, 133, 183)
Not very good. Impurities produce great effect								
$(CH_3)_2CO$	Acetone.....	21.3 ±0.1	−0.096 ± 2	0	0	4	8	(34, 49, 75, 95, 189, 191)
Dispersion bands in range 4.3 × 10^8 to 4.6 × 10^8 (34)								
$C_6H_4CH_3NO_2$	*o*-Nitrotoluene..	27.42 ±0.1	−0.15	Audio				(183)
Value not known accurately at higher frequencies								
$C_6H_5NO_2$	Nitrobenzene...	35.7 ±0.3	−0.18	0	0	1	6	(92, 183, 191)

Table 2.—Dielectric Constant (ϵ) of Pure Organic Gases and Vapors: Pressure of 1 Normal Atmosphere; $\epsilon = 1 + \Delta \times 10^{-3}$

℃-Table. The ℃-Arrangement; *v.* Vol. III, p. viii

		Δ	t, °C	Lit.
CCl_4	Carbon tetrachloride....	3.0	110	(10)
		2.7	110	(160.1)
$CHCl_3$	Chloroform.....	4.2	120	(10)
		3.8	10	(160.1)
CH_2Cl_2	Methylene chloride....	6.5	100	(10)
		6.0	100	(160.1)
CH_3Br	Methyl bromide.....	6.8	100	(142)
CH_3Cl	Methyl chloride.....	6.9	100	(142)
		6.4	100	(160.1)
CH_3I	Methyl iodide.....	6.3	100	(142)
CH_3NO_2	Nitromethane.....	24.7	100	(142)
CH_4	Methane.....	0.94*	0	(21.1, 107, 148.1)
		0.89	0	(142)
		1.01	0	(160.1)

Table 2.—(*Continued*)

		Δ	t, °C	Lit.
CH_4O	Methyl alcohol.....	5.7	100	(142)
		6.1	100	(10, 97, 113)
CH_5N	Methylamine.....	3.8	100	(142)
C_2H_2	Acetylene.....	1.34*	0	(173.1)
C_2H_3Br	Vinyl bromide.....	8.1	20	(142)
C_2H_3ClO	Acetyl chloride.....	21.7	20	(142)
C_2H_3N	Acetonitrile.....	26.4	100	(142)
C_2H_4	Ethylene.....	1.44±1	0	(107, 142, 173.1)
C_2H_4O	Acetaldehyde.....	21.3	20	(142)
$C_2H_4O_2$	Methyl formate.....	7.3	100	(113)
C_2H_5Br	Ethyl bromide.....	14.6	15.5	(107)
		13.9	20	(142)
		8.9	100	(142)
C_2H_5Cl	Ethyl chloride.....	14.7	15.5	(107)
		13.2	20	(142)
		8.5	100	(142)
C_2H_5I	Ethyl iodide.....	14.0	20	(142)
		8.9	100	(142)
$C_2H_5NO_2$	Nitroethane.....	28.1	100	(142)
C_2H_6	Ethane.....	1.50*	0	(173.1)
C_2H_6O	Ethyl alcohol.....	6.5	100	(10)
		6.9	100	(113)
		6.1	100	(142)
C_2H_6O	Methyl ether.....	7.4	0	(10)
		4.1	100	(142)
C_2H_7N	Dimethylamine.....	3.3	100	(142)
C_2H_7N	Ethylamine.....	4.3	100	(142)
C_3H_5Br	3-Bromopropylene.....	12.9	20	(142)
C_3H_5Cl	2-Chloropropylene.....	10.2	20	(142)
C_3H_5Cl	3-Chloropropylene.....	12.8	20	(142)
C_3H_5N	Propionitrile.....	28.3	100	(142)
C_3H_6O	Acetone.....	25.9	20	(142)
		15.9	100	(142)
$C_3H_6O_2$	Ethyl formate.....	8.3	100	(113)
$C_3H_6O_2$	Methyl acetate.....	7.7	100	(113)
C_3H_7Br	*n*-Propyl bromide.....	9.8	100	(142)
C_3H_7Cl	Isopropyl chloride.....	15.2	20	(142)
		9.8	100	(142)
C_3H_7Cl	*n*-Propyl chloride.....	14.3	20	(142)
		9.3	100	(142)
C_3H_7N	Allylamine.....	4.2	100	(142)
C_3H_9N	*n*-Propylamine.....	5.0	100	(142)
C_4H_8	Butylene.....	3.19	0	(173.1)
		2.91	21	(173.1)
		2.22	100	(173.1)
		1.74	193	(173.1)
C_4H_9Cl	*n*-Butyl chloride.....	10.1	100	(142)
$C_4H_{10}O$	Ethyl ether.....	7.0	16.5	(107)
		4.9	100	(113)
		5.2	100	(10)
$C_4H_{11}N$	Diethylamine.....	3.8	100	(142)
C_5H_{10}	β-Amylene.....	2.8	100	(142)
C_5H_{10}	2-Methyl-2-butene.....	2.8	100	(142)
$C_5H_{10}O_2$	Ethyl propionate.....	14.0	120	(113)
C_5H_{12}	*n*-Pentane.....	2.5	100	(142)
C_5H_{12}	Isopropylethane.....	2.6	100	(142)
C_6H_6	Benzene.....	2.8	100	(10, 113, 142)
$C_6H_{15}N$	Triethylamine.....	4.2	100	(142)
C_7H_8	Toluene.....	4.3	126	(113)
C_7H_{16}	*n*-Heptane.....	3.5	100	(142)

* $(\epsilon - 1)$ is proportional to p/T, p = pressure, T = absolute temperature.

TABLE 3.—DIELECTRIC CONSTANT (ϵ) OF MIXTURES OF HYDROGEN AND NITROGEN (178, 179)

Audio frequency; 20°C; P_{H_2}, P_{N_2} = partial pressures of the H_2, N_2; P = total pressure of the mixture. Unit of P, P_{H_2}, P_{N_2} = 1 atmosphere; of ϵ = 1 cgse unit.

P	P_{H_2}	P_{N_2}	ϵ	P	P_{H_2}	P_{N_2}	ϵ
1.0	0.7	0.3	1.0003	39.0	14.0	24.8	1.0172
1.0	0.6	0.4	1.0004	39.3	24.8	14.3	1.0138
1.0	0.4	0.6	1.0004	39.8	27.6	11.9	1.0133
20.4	14.2	6.2	1.0069	55.9	38.8	16.6	1.0186
20.7	7.4	13.3	1.0092	58.5	21.0	36.9	1.0255
20.8	13.1	7.7	1.0074	60.3	38.0	21.7	1.0211

TABLE 4.—DIELECTRIC CONSTANT (ϵ) OF PURE ORGANIC COMPOUNDS, AND ITS VARIATION WITH TEMPERATURE (t) AND FREQUENCY (ν): LIQUIDS AND SOLIDS

All values of ϵ have been reduced to a basis which accords with the values given for the standard liquids in Table 1.

For symbols, *see* p. 82; also, B. P. = boiling point, crit. = critical temperature, M. P. = melting point, *vp* = liquid is under pressure of its saturated vapor. $\nu = A \times 10^n$. Unit of ϵ = 1 cgse unit; of ν = 1 cycle/sec; of t = 1°C.

C-Table. The C-Arrangement; *v.* Vol. III, p viii

Immediately after oleic acid are data for a few oleates. Some metallic organic compounds are also given in the table.

ϵ	t	A	n	Lit.
	CCl_4, Carbon tetrachloride			
2.24*	20	1	3; 8	(77, 80, 99, 183)
2.10	76.7 B. P.	Audio		(76)
	CN_4O_8, Tetranitromethane			
2.13	20	Audio		(191)
2.15	5	Audio		(191)
<2.2	20	4	8	(189)
	CHN, Hydrocyanic acid			
95 ± 4*l*	+ 21	3.6	8	(163)
2.4*s*	− 25	3.6	8	(162)
3.05*s*	− 70	3.6	8	(162)
	$CHBr_3$, Bromoform; M. P. = 7.5°			
4.51 ± 5	20	Audio		(28, 183)
4.65 ± 5	8			(28)
4.45 ± 0.1	20	4	8	(41, 49)
4.73	25	1	6	(161.2)
	$CHCl_3$, Chloroform; M. P. = −63.2°			
5.05 ± 5†	20	Audio		(28, 42, 77, 116, 133, 136, 183)
2.76	−186			(87)
3.10	− 80			(87)
3.12	− 70			(87)
7.03	− 60			(87)
6.47	− 40			(87)
6.65	− 40			(77)
5.95	− 20			(17, 87)
6.00	− 20			(77)
5.48	0			(17, 87, 145)
5.49	0			(77)
5.05 ± 0.1	+ 20			(28, 42, 116, 133, 136, 183)
4.70	40			(87, 145, 177)
4.37	60			(76, 87, 145, 177)

* $\partial_t = -0.14$ (20 *t* 60) (77). † $\partial_{20} = -1.85$ (28, 87, 127).

TABLE 4.—*Continued*)

ϵ	t	A	n	Lit.
	$CHCl_3$.—(*Continued*)			
3.85	100			(177)
3.46	140			(177)
3.05	180			(177)
4.95 ± 0.1	20	1	6	(87, 95)
4.93	20	6.7	7	(193.1)
4.95 ± 0.1	20	4	8	(49, 99)
	CH_2I_2, Methylene iodide			
5.5 ± 0.1	19	Audio		(183)
5.1	21	5	8	(41)
	CH_2O_2, Formic acid; M. P. = 8.4°			
62.0	15	2.5	7	(181)
2.41	−187			(38)
2.66	−182			(38)
2.70	−137			(38)
3.65	−118			(38)
4.80	−112			(38)
19.0*s**	+ 2	4	8	(49)
58.5†	16	4	8	(49)
47.9	18.5	5	8	(41)
	CH_3I, Methyl iodide			
7.1 ± 0.1	20	Audio		(183)
6.48	42.35 B. P.	Audio		(76)
	CH_3NO, Formamide			
>84	20	4	8	(189)
	CH_3NO_2, Nitromethane			
39.4 ± 2	20	Audio		(191)
45.2	0	Audio		(191)
27.75 ± 0.1	101 B. P.	Audio		(76)
38.9 ± 8	20	4	8	(164, 189)
	CH_3NO_3, Methyl nitrate			
23.9 ± 5	18	3.6	8	(164)
	CH_4N_2O, Urea			
3.5 ± 2	22	4	8	(174)
	CH_4O, Methyl alcohol; M. P. = −95° (*see also* Table 6)			
33.7 ± 1.0‡	20	1	2; 6	(2, 64, 95, 110, 180)
3.25	−185			(38)
3.55	−170			(38)
4.0	−160			(38)
5.05	−140			(38)
66.8	−110			(2)
56.6	− 80			(2)
48.5	− 50			(2)
41.8	− 20			(2)
37.5	0			(2)
33.7 ± 1.0	+ 20			(2, 64, 95, 110, 180)
33.1 ± 0.5	20	4	8	(44, 49, 190)
12.4	17	5	9	(53)
25	17	7	9	(125)
10.8	17	8	9	(53)
7.9	17	17	9	(53)
	CH_5N, Methylamine			
<10.5	21	3.6	8	(164)
	C_2Cl_4, Tetrachloroethylene			
2.37	16	6.7	7	(194)
2.46	21	3.6	8	(164)
	C_2N_2, Cyanogen			
2.57 ± 5*l*	23	3.6	8	(164)

* $k' = 0.17$ (49). † $k' = 0.08$ (49).
‡ $\partial_{20} = -18$, $A = 1$; $n = 3$; 8 (2, 160).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_2HBr_3O, Bromal			
7.6±2	21	5	8	(41)
	C_2HCl_3, Trichloroethylene			
3.42±3	16	6.7	7	(194)
	C_2HCl_3O, Chloral; M. P. = −57.5°			
7.58	− 40			(127)
6.54	− 20			(127)
5.60	0			(127)
4.94	+ 20			(127)
4.56	40			(127)
4.25	60			(127)
5.0	20	1	*ca.* 6	(127)
5.5	15	2.5	7	(181)
	$C_2HCl_3O_2$, Trichloroacetic acid			
4.55	61	Audio		(191)
	C_2HCl_5, Pentachloroethane			
3.76	16	6.7	7	(194)
3.60	25	1	6	(161.2)
	$C_2H_2Br_2O$, Bromoacetyl bromide			
12.6±2	20	4	8	(189)
	$C_2H_2Br_4$, Tetrabromoethane			
7.1	20	Audio		(191)
8.6	2.5	Audio		(191)
	$C_2H_2Cl_2$, Dichloroethylene			
3.67*†	16	6.7	7	(194)
7.55*‡	16	6.7	7	(194)
9.22§	*ca.* 20	4	5	(61.1)
2.25‖	*ca.* 20	4	5	(61.1)
	$C_2H_2I_2$, Diiodoethylene			
4.46¶	83	4	5	(61.1)
3.19**	83	4	5	(61.1)
	$C_2H_2Cl_2O_2$, Dichloroacetic acid			
8.8*l*	− 10	Audio		(191)
8.2*l*	+ 20	Audio		(191)
7.8*l*	60	Audio		(191)
8.1*s*		Audio		(191)
10.7	20	5	8	(41)
	$C_2H_2Cl_4$, *sym.*-Tetrachloroethane			
7.83	25	1	6	(161.2)
8.20	20	6.7	7	(193.1, 194)
	C_2H_3BrO, Acetyl bromide			
16.5±3	20	4	8	(189)
	C_2H_3ClO, Acetyl chloride			
15.9	20	Audio		(191)
17.0	0	Audio		(191)
15.8±3	20	4	8	(189)
25.3	15	2.5	7	(181)
	$C_2H_3ClO_2$, Chloroacetic acid			
ca. 21*s*	20	Audio		(191)
ca. 20.0*l*	62	Audio		(191)
	$C_2H_3Cl_3O_2$, Chloral hydrate			
13*l*††	65	4	8	(49)
3.3±2*s*‡‡	20	4	8	(49, 174)
	C_2H_3N, Acetonitrile			
42.0	0	Audio		(191)
38.8	20	Audio		(76, 191)
26.2	81.6 B. P.	Audio		(76)
36.2±7	20	4	8	(163, 189)

* Mixtures in which the *cis* and *trans* forms were separated as far as possible.
† *Cis*. ‡ *Trans*. § *Cis*, pure, B. P. = 60.25°. ‖ *Trans*, pure, B. P. = 48.35°.
¶ *Cis*, M. P. = −13.8°.
** *Trans*, M. P. = +72°.
†† $k' = 0.03$.
‡‡ $k' = < 0.02$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_2H_3NO, Glycolic nitrile			
69±1	20	4	8	(189)
	C_2H_3NS, Methyl thiocyanate			
35.9±7	20	4	8	(54, 124, 189)
	C_2H_3NS, Methyl isothiocyanate			
19.7±7	37	4	8	(54, 124, 189)
	$C_2H_4Br_2$, Ethylene bromide; M. P. = +10°			
4.865±0.015	18	Audio		(42, 91, 183)
2.69	−185			(68)
2.70	−150			(68)
2.77	− 80			(68)
2.94	− 60			(68)
2.97	− 50			(68)
2.98	− 30			(68)
4.865±.015	+ 18			(42, 91, 183)
4.09	131.3 B. P.			(76)
4.70	25	1	6	(161.2)
6.3	20	5	8	(41)
	$C_2H_4Cl_2$ Ethylene chloride; M. P. = −35.5°			
10.5±3	20	1	3; 6	(95, 110, 183, 187, 191)
11.6	0	Audio		(191)
10.44	20	Audio		(191)
10.13	25	1	3	(80.1)
9.4	50	Audio		(191)
9.96	20	6.7	7	(193.1)
9.3	20	5	8	(41)
	$C_2H_4Cl_2$, Ethylidene chloride			
10.9	16	Audio		(110)
9.1	18	5	8	(41)
	C_2H_4O, Acetaldehyde			
21.6±4	20	4	8	(49, 190)
22.2±4	10	4	8	(49)
	C_2H_4O, Ethylene oxide			
13.9	− 1	Audio		(191)
	C_2H_4OS, Thioacetic acid			
13.0	20	4	8	(189)
17.3	21	3.6	8	(54)
	$C_2H_4O_2$, Acetic acid			
7.14±0.1	17	Audio		(91)
7.1	17	1.3	8	(44)
6.4±1*	20	4	8	(41, 44, 49)
4.1*s*†	2	4	8	(49)
	$C_2H_4O_2$, Methyl formate			
8.27	20	Audio		(191)
9.25	0	Audio		(191)
8.9	+ 19	4	8	(49)
2.56	−194	4.7	5	(89)
	C_2H_5Br, Ethyl bromide			
9.45	20	1	3; 6	(80, 183, 191)
10.5	1.4	Audio		(191)
8.81	38.4 B. P.	Audio		(76)
9.1±3	18	4	8	(49)
	C_2H_5Cl, Ethyl chloride			
6.29*vp*	170	Audio		(62)
6.06*vp*	179	Audio		(62)
5.60*vp*	180	Audio		(62)
4.68*vp*	185.5 crit.	Audio		(62)

* $k' = 0.07$.
† $k' = 0.19$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_2H_5ClO, Ethylenechlorohydrin			
25.8	24.5	Audio		(76)
13.2	132.0 B. P.	Audio		(76)
	C_2H_5I, Ethyl iodide			
7.4±1	20	Audio		(49)
7.4±1	20	4	8	(49)
	C_2H_5NO, Acetaldoxime			
2.98	22.6	Audio		(191)
3.4	20	4	8	(41, 189)
	C_2H_5NO, Acetamide			
60.3±1.0*l*	83 M. P.	4	8	(189)
60.4±1.0*l*‡	77	4	8	(189)
4.0*s*	20	4	8	(189)
7.2*s*	22	4	8	(174)
	$C_2H_5NO_2$, Nitroethane			
30.0±6	18	3.6	8	(164)
	$C_2H_5NO_3$, Ethyl nitrate; M. P. = −112°			
19.7	20	Audio		(49, 189, 191)
2.73	−190	1.2	2	(38)
2.92	−176	1.2	2	(38)
21.3	0	Audio		(191)
19.7	+ 20	Audio		(49, 189, 191)
17.2	50	Audio		(191)
19.7±3	20	4	8	(49, 189)
	$C_2H_6N_2O$, Nitrosodimethylamine			
54±1	20	4	8	(189)
C_2H_6O, Ethyl alcohol; M. P. = −114° (*see also* Fig. 2 and Table 6)				
25.7±2*	20	Audio		(76, 110, 133, 183, 191)
3.12*s*	−172			(37)
2.7*s*	< −150			(2)
55.5	−120			(2)
45.1	− 80			(2)
38.1	− 50			(2)
32.4	− 20			(2)
28.9	0			(145, 191)
25.7±2	+ 20			(76, 110, 133, 183, 191)
22.7	40			(145, 191)
20.2	60			(145, 191)
23.2±5	20	1	6	(135, 124.1)
23.9	20	6	7	(64)
24.2±7	20	2.5	7	(181)
22.0±4†	+ 20	4	8	(49, 174, 190)
3.12	−170	1	2	(37)
	$C_2H_6O_2$, Glycol			
47.0	0	Audio		(191)
41.2	20	Audio		(191)
35.6	50	Audio		(191)
35.2±7	20	4	8	(190)
	$C_2H_6O_4S$, Dimethyl sulfate			
55.0	20	Audio		(191)
58.9	0	Audio		(191)
47.4±9	20	4	8	(189)
	C_2H_6S, Dimethyl sulfide			
6.3±2	20	4	8	(189)
	C_2H_6S, Ethylmercaptan			
8.0	*ca.* 20	4	8	(9)
	C_2H_7N, Ethylamine			
6.3±2	21	3.6	8	(164)

* $\partial_{20} = -16$ (2, 76, 135, 145, 191). † $k' = 0.21$ (49, 174, 190) ‡ Supercooled.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_2H_8N_2$, Ethylenediamine			
16.0±4	18	3.6	8	(124)
	$C_3H_2N_2$, Malonic nitrile			
47.2±9	36	3.6	8	(54)
	$C_3H_3NO_2$, Cyanoacetic acid			
ca. 33.4	4	Audio		(191)
	$C_3H_4Cl_2O$, 1, 1-Dichloroacetone			
14.6	20	5	8	(41)
	C_3H_5Br, Allyl bromide			
7.0	19	Audio		(191)
7.4	1	Audio		(191)
	$C_3H_5BrO_2$, α-Bromopropionic acid			
11.0±3	20	5	8	(41)
	$C_3H_5Br_3$, 1, 2, 3-Tribromopropane			
6.4	20	5	8	(41)
	C_3H_5Cl, Allyl chloride			
8.2	20	Audio		(191)
8.7	1	Audio		(191)
7.3	20	5	8	(41)
	C_3H_5ClO, Chloroacetone			
29.8±6	20	5	8	(41)
	C_3H_5ClO, Epichlorohydrin			
25.7	0	Audio		(191)
22.9	20	Audio		(191)
21.2	20	5	8	(41)
	$C_3H_5ClO_2$, Ethyl chloroformate			
11.3±3	20	4	8	(41, 189)
	$C_3H_5ClO_2$, Methyl chloroacetate			
12.9±4	20	5	8	(41)
	$C_3H_5Cl_3$, 1, 2, 3-Trichloropropane			
7.5	21	5	8	(41)
	C_3H_5I, Allyl iodide			
6.1	19	5	8	(41)
	C_3H_5N, Propionitrile			
31.6	0	Audio		(191)
27.7	20	Audio		(191)
24.6	50	Audio		(191)
27.5±5	20	4	8	(9, 163, 189)
	C_3H_5NO, Lactonitrile			
38.4±7	20	4	8	(189)
	C_3H_5NS, Ethyl thiocyanate			
35.3	0	Audio		(191)
29.6	20	Audio		(191)
29.2±5	20	3.6	8	(54, 124)
27.0	20	4	8	(189)
	C_3H_5NS, Ethyl isothiocyanate			
23.8	0	Audio		(191)
19.7	20	Audio		(191)
19.7±4	20	4	8	(54, 124, 189)
	$C_3H_6Br_2$, 1, 2-Dibromopropane			
4.35±0.1	20	5	8	(41)
	$C_3H_6Br_2O$, 1, 2-Dibromopropyl alcohol			
9.1±2	21	5	8	(41)
	$C_3H_6Cl_2O$, 1, 1-Dichloroisopropyl alcohol			
12.0±3	20	5	8	(41)
	C_3H_6O, Allyl alcohol			
21.0±4*	21	4	8	(41, 48, 49)
21.6±6	15	2.5	7	(181)
	C_3H_6O, Propionaldehyde			
18.9±4	17	4	8	(49)
14.4	15	2.5	7	(181)

* $k' = 0.07$.

TABLE 4.—(*Continued*)

ϵ	t.	A	n	Lit.
C_3H_6O, Acetone; M. P. = −94.3°; for dispersion and absorption, *see* (34)				
21.4*	+ 20	Audio		(191)
2.62	−184			(38)
2.49	−181			(38)
2.66	−151.5			(38)
4.63	−129			(38)
31.0	− 80			(1)
27.9	− 50			(1)
26.1	− 30			(75)
23.3	0			(75)
21.4±1	+ 20			(34, 49, 75, 95, 181, 189, 191)
18.7	50			(75)
17.68	56.15 B. P.	Audio		(76)
21.9±6	20	1	6	(75, 95, 124.1)
21.3	20	2.5	7	(181)
21.22	20	4	8; 9	(34, 49, 189)
$C_3H_6O_2$, Propionic acid				
3.19	19	Audio		(91)
3.21±6†	17	4	8	(41, 49)
$C_3H_6O_2$, Ethyl formate				
9.1	14	Audio		(110, 180)
8.4±1	+ 19	4	8	(49)
2.40	−192	4.7	5	(89)
$C_3H_6O_2$, Methyl acetate				
7.3±2‡	20	Audio		(110, 119, 180)
7.2±2	20	4	8	(49)
$C_3H_6O_3$, Lactic acid				
23 ±1	19	Audio		(119)
19.4±2§	19	4	8	(49)
C_3H_7Br, Propyl bromide				
7.2±2	20	5	8	(41)
C_3H_7Cl, Propyl chloride				
7.7±2	20	5	8	(41)
$C_3H_7ClO_2$, 3-Chloro-1, 2-dihydroxypropane				
31	20	Audio		(191)
38.6	0	Audio		(191)
15.1	20	5	8	(41)
$C_3H_7NO_2$, Urethane				
13.8±2*l*	60	3.6	8	(164)
3.24±6*s*	23	3.6	8	(164)
$C_3H_7NO_2$, Isopropyl nitrite				
ca. 11.5	19	3.6	8	(164)
$C_3H_7NO_3$, Propyl nitrate				
14.2±3	18	3.6	8	(164)
C_3H_8O, *n*-Propyl alcohol; M. P. = −127° (*see also* Table 6)				
21.8±4‖	20	Audio		(2, 76, 110, 180)
2.75*s*	<−150			(2)
47.0	−126			(2)
41.0	−100			(2)
37.1	− 80			(2)
32.0	− 50			(2)
27.1	− 20			(2)
24.5	0			(2)

* $\partial_{20} = -9.6\pm2$ (1, 48, 75, 191).
† $\kappa = 0.03$.
‡ $\partial_{20} = -6$ (119). § $k' = 0.25$. ‖ $\partial_{20} = -13$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
C_3H_8O.—(*Continued*)				
21.8±4	+ 20			(2, 76, 110, 180)
11.83	97.19 B. P.			(76)
19.8	20	2.5	7	(181)
12.3±5*	20	4	8	(49, 160, 174)
C_3H_8O, Isopropyl alcohol				
26 ±1	20	Audio		(119)
19.8	15	2.5	7	(181)
15.7±5	20	4	8	(48, 49)
$C_3H_8O_2$, Methylal				
2.7	20	4	8	(189)
$C_3H_8O_3$, Glycerol (*see* Table 5)				
$C_3H_9BO_3$, Trimethyl borate				
8.2±2	20	4	8	(189)
C_3H_9N, Isopropylamine				
5.5±1	20	3.6	8	(164)
C_3H_9N, Trimethylamine				
2.99±4	4	3.6	8	(164)
$C_4H_2O_3$, Maleic anhydride				
51.0 ±1.0	60	4	8	(189)
$C_4H_4N_2$, Ethylene cyanide				
58.3 ±1.0	58	4	8	(189)
62.4 ±1.2*l*	60	3.6	8	(164)
66.6 ±1.3*s*	23	3.6	8	(164)
C_4H_4S, Thiophene				
2.76±5	16	Audio		(183)
2.80	20	3.6	8	(54)
2.60	50	3.6	8	(54)
$C_4H_5Cl_3O$, Butyl chloral				
10.0	18	5	8	(41)
$C_4H_5Cl_3O_2$, Ethyl trichloroacetate				
8.4	0	Audio		(191)
7.8	20	Audio		(191)
6.7	60	Audio		(191)
C_4H_5N, Crotonic nitrile				
36.1†‡	*ca.* 20	4	5	(61.1)
28.1†§	*ca.* 20	4	5	(61.1)
$C_4H_5NO_2$, Methyl cyanoacetate				
29.4±6	20	4	8	(189)
C_4H_5NS, Allyl isothiocyanate				
17.5±3	18	3.6	8	(54, 124)
$C_4H_6Cl_2O_2$, Ethyl dichloroacetate				
11.7	0	Audio		(191)
10.4	20	Audio		(191)
$C_4H_6O_3$, Acetic anhydride				
20.5	20	Audio		(191)
22.5	0	Audio		(191)
18.3±4	20	4	8	(189)
20.0	20	5	8	(41)
$C_4H_6O_4$, Dimethyl oxalate				
ca. 9.2*l*	65	4	8	(49)
ca. 3.1*s*	20	4	8	(49)
$C_4H_6O_6$, Tartaric acid				
35.9	15	2.5	7	(181)
C_4H_7Br, *sym.*-Dimethylbromoethylene				
6.76‖	*ca.* 20	4	5	(61.1)
5.38¶	*ca.* 20	4	5	(61.1)

* $k' = 0.41$.
† CH_3, CN, *cis*, *trans* isomers.
‡ B. P. = 107.7; 108.2°. § B. P. = 121.7; 122.1°.
‖ CH_3 and Br in *trans*, B. P. = 93.6; 93.9°.
¶ CH_3 and Br in *cis*, B. P. = 85.8; 85.9°.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_4H_7Br, 1-Bromobutylene			
5.89*†	*ca.* 20	4	5	(61.1)
5.05*‡	*ca.* 20	4	5	(61.1)
	$C_4H_7BrO_2$, 1-Bromobutyric acid			
7.22	20	5	8	(41)
	$C_4H_7BrO_2$, 1-Bromoisobutyric acid (supercooled)			
9.3*l*	<29	5	8	(41)
	$C_4H_7ClO_2$, Ethyl chloroacetate			
11.6	20	5	8	(41)
	$C_4H_7ClO_2$, Propyl chloroformate			
11.2	20	5	8	(41)
	C_4H_7N, Butyronitrile; slight absorption			
20.7±4	21	3.6	5	(163)
	C_4H_7N, Isobutyronitrile; slight absorption			
20.8±4	24	3.6	5	(163)
	$C_4H_8Br_2$, 2, 3-Dibromobutane			
5.70±0.1	20	5	8	(41)
	$C_4H_8Br_2$, Isobutylene bromide			
4.05±0.1	20	5	8	(41)
	$C_4H_8N_2O_2$, Succinamide			
2.9±2	22	4	8	(174)
	C_4H_8O, Butyraldehyde			
13.4	26	Audio		(76)
10.78	77.0 B. P.	Audio		(76)
	C_4H_8O, Methyl ethyl ketone			
18.45±0.1	23	Audio		(76)
14.46	79.6 B. P.	Audio		(76)
18.4±4	15	2.5	7	(181)
18.1±3	17	4	8	(49)
	$C_4H_8O_2$, *n*-Butyric acid			
2.93±4	16	Audio		(91)
2.85±6	20	4	8	(41, 49)
	$C_4H_8O_2$, Isobutyric acid			
2.68	16	Audio		(91)
2.65±5	20	4	8	(49)
3.22	20	5	8	(41)
	$C_4H_8O_2$, Ethyl acetate			
6.4±1§	20	Audio		(76, 110, 116, 119, 180)
5.30	77.15 B. P.	Audio		(76)
6.0±1	+20	4	8	(49)
2.48	−194	4.7	5	(89)
	$C_4H_8O_2$, Methyl propionate			
5.47±0.1	19	5	8	(41)
	$C_4H_8O_2$, Propyl formate			
9.10	23	Audio		(110)
7.9±2	+19	4	8	(49)
2.39	−193.5	4.7	5	(89)
	C_4H_9Br, *n*-Butyl bromide			
6.60±0.1	19.8	5	8	(41)
	C_4H_9Br, Isobutyl bromide			
6.65±0.1	20.7	5	8	(41)
	C_4H_9Br, *tert.*-Butyl bromide			
8.55±0.15	20.4	5	8	(41)
	C_4H_9Cl, Butyl chloride			
9.65		Audio		(119)
	C_4H_9Cl, Isobutyl chloride			
7.1		Audio		(119)
	C_4H_9I, *n*-Butyl iodide			
6.15±0.1	25	Audio		(76)
4.52±0.1	129.9 B. P.	Audio		(76)

* *Cis, trans* isomers.
‡ B. P. = 86.0; 86.2°.
† B. P. = 94.6; 94.8°.
§ $\partial_{20} = -1.5$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_4H_9I, Isobutyl iodide			
5.8±0.1	20	5	8	(41)
	C_4H_9I, *tert.*-Butyl iodide			
6.3±0.1	20	5	8	(41)
	C_4H_9NO, Methyl ethyl ketoxime			
3.4	20	5	8	(41)
	$C_4H_9NO_3$, Isobutyl nitrate			
11.9±2	19	3.6	8	(164)
	$C_4H_{10}Hg$, Mercury diethyl			
2.3±2	20	4	8	(124, 189)
	$C_4H_{10}O$, *n*-Butyl alcohol			
17.8±2	25	Audio		(76, 119)
8.19	117.7 B. P.	Audio		(76)
7.8±5*	19	4	8	(48, 49)
$C_4H_{10}O$, Isobutyl alcohol; M. P. = −108° (*see also* Table 6)				
18.7±4†	20	Audio		(2, 91, 110, 183)
2.78	<−150			(2)
30.2	−102			(2)
34.2	− 95			(2)
31.7	− 80			(2)
27.0	− 50			(2)
22.8	− 20			(2)
20.5	0			(2)
18.7±4	+ 20			(2, 91, 110, 183)
8.0	18	3	8	(160)
6.2§	18	4	8	(48, 49)
	$C_4H_{10}O$, *sec.*-Butyl alcohol			
15.5	19	Audio		(119)
11.6±2‖	19	4	8	(48, 49)
	$C_4H_{10}O$, *tert.*-Butyl alcohol			
11.4	19	Audio		(119)
6.6±1¶	19	4	8	(48, 49)
	$C_4H_{10}O$, Ethyl ether; M. P. = −116°			
4.335±5**	20	Audio		(17, 42, 63, 133, 136, 139, 177, 183)
1.650	−186	Audio		(87)
2.3	−180	1.2	2	(38)
1.655	−160	Audio		(87)
3.7	−155	1.2	2	(38)
1.752	−130	Audio		(87)
2.100	−120	Audio		(87)
3.750	−115	Audio		(87)
7.51	−110	Audio		(87)
8.95	−108	Audio		(87)
8.143	−100	Audio		(87)
7.05	− 80	Audio		(87)
6.33	− 60	Audio		(1, 87)
6.10	− 60			(127)
5.72	− 40	Audio		(1, 87)
5.53	− 40			(127)
5.15	− 20	Audio		(1, 87)
5.08	− 20			(127)
4.683	0	Audio		(1, 87)
4.68	0			(127)

* $k' = 0.45$.
† $\partial_{20} = -9.5$.
§ $k' = 0.47$.
‖ $k' = 0.33$.
¶ $k' = 0.40$.
** $\partial_{20} = -1.9$, $n = 3$; 6 (17, 87, 145, 177, 183).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_4H_{10}O$.—(*Continued*)			
4.335±5	+ 20	Audio		(17, 42, 63, 133, 136, 139, 177, 183)
4.11	34.54 B. P.	Audio		(76)
3.96	40	Audio		(63, 177)
3.40	80	Audio		(63, 177)
2.90	120	Audio		(63, 177)
2.40	160	Audio		(63, 177)
2.13	180	Audio		(63, 177)
1.93	190	Audio		(63, 177)
1.80	192	Audio		(63, 177)
1.6	194	Audio		(63, 177)
1.54	200	Audio		(63, 177)
1.54	250	Audio		(63, 177)
4.32	20	6	4	(86)
4.351	20	6	5	(87)
4.28±3	20	1	6	(124.1, 127, 161.2)
4.36±2	20	4	8	(49)
3.26	20	7	9	(125)
	$C_4H_{10}O_3S$, *sym.*-Diethyl sulfite			
17.6	0	Audio		(191)
15.9	20	Audio		(191)
13.7	50	Audio		(191)
16.0±2	20	4	8	(190)
	$C_4H_{10}O_3S$, *asym.*-Diethyl sulfite			
45.7	0	Audio		(191)
41.9	20	Audio		(191)
39.4±8	20	4	8	(190)
	$C_4H_{10}S$, Diethyl sulfide			
7.2	*ca.* 20	4	8	(9)
	$C_4H_{10}S_2$, Diethyl disulfide			
15.9±3	19	3.6	8	(54)
	$C_4H_{11}N$, *n*-Butylamine			
5.4±1	21	3.6	8	(164)
	$C_4H_{11}N$, Diethylamine			
3.7±1	20	3.6	8	(124, 164)
5.5	19	5	8	(41)
	$C_4H_{11}N$, Isobutylamine			
4.52±8	21	3.6	8	(164)
	$C_4H_{12}O_4Si$, Tetramethyl silicate			
6.0	*ca.* 20	3.6	8	(124)
	$C_5H_4O_2$, Furfuraldehyde			
47.2	0	Audio		(191)
41.9	20	Audio		(191)
34.9	50	Audio		(191)
39 ± 2	20	4	8	(49, 190)
	$C_5H_4O_3$, Citraconic anhydride			
40.3±8	20	4	8	(189)
	C_5H_5N, Pyridine			
12.5	20	Audio		(28, 76)
11.4	50	Audio		(28)
10.6	80	Audio		(28)
9.38	115.5 B. P.	Audio		(28, 76)
12.5	20	6.7	7	(193.1)
12.4±2	20	4	8	(41, 99, 124, 163)
	$C_5H_7NO_2$, Ethyl cyanoacetate			
27.7	21	Audio		(191)
27.0±3*	20	4	8	(49, 189)

* $k' = 0.06$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_5H_7NO_2$, 1-Cyanoethyl acetate			
19.3±4	20	4	8	(189)
	$C_5H_8O_2$, Acetylacetone			
26.0	0	Audio		(191)
23.1	20	Audio		(191)
25.9±5	20	4	8	(49, 54, 189)
	$C_5H_8O_4$, Dimethyl malonate			
10.4±2	20	4	8	(41, 189)
	$C_5H_9BrO_2$, 1-Bromoisovaleric acid			
6.5	20	5	8	(41)
	$C_5H_9BrO_2$, Ethyl 1-bromopropionate			
10.1	0	Audio		(191)
9.4	20	Audio		(191)
8.9±2	20	5	8	(41)
	$C_5H_9ClO_2$, Ethyl 1-chloropropionate			
10.1	20	5	8	(41)
	$C_5H_9ClO_2$, Isobutyl chloroformate			
9.2	20	5	8	(41)
	$C_5H_9IO_2$, Ethyl 2-iodopropionate			
8.8±2	20	5	8	(41)
	C_5H_9N, *n*-Valeronitrile; slight absorption			
17.7±3	21	3.6	8	(163)
	C_5H_9N, Isobutyl cyanide; slight absorption			
18.3±4	22	3.6	8	(163)
	C_5H_{10}, Amylene			
2.23	16	Audio		(110)
2.07	21	Audio		(42)
6.9(?)	22	3.6	8	(124)
	$C_5H_{10}Br_2$, Amylene bromide			
5.64±5	15	Audio		(91)
	$C_5H_{10}O$, Valeraldehyde			
11.8	15	2.5	7	(181)
10.3	17	4	8	(49)
	$C_5H_{10}O$, Diethyl ketone			
17.3	15	4	8	(49)
	$C_5H_{10}O$, Methyl propyl ketone			
16.8	15	2.5	7	(181)
15.4	17	4	8	(49)
	$C_5H_{10}O_2$, Valeric acid			
2.68	17	Audio		(91)
2.68±5	18	4	8	(41, 49)
	$C_5H_{10}O_2$, Isovaleric acid			
2.79±5	20	4	8	(49)
	$C_5H_{10}O_2$, *n*-Butyl formate			
2.43	−194.3	4.7	5	(89)
	$C_5H_{10}O_2$, Ethyl propionate			
5.76 ±0.1	20	Audio		(119, 180)
5.76 ±0.1	20	4	8	(49)
5.0	20	5	8	(41)
	$C_5H_{10}O_2$, Isobutyl formate			
8.4	13.5	3.8	1	(180)
7.35	23	Audio		(110)
6.5±1	19	4	8	(49)
$k'_{20} = 0.008$		2	8	(35)
	$C_5H_{10}O_2$, Methyl butyrate			
5.6	20	5	8	(41)
	$C_5H_{10}O_2$, Propyl acetate			
6.3±3*	20	Audio		(110, 119, 180)
5.8±1	+ 19	4	8	(49)
2.42	−192	4.7	5	(89)
	$C_5H_{10}O_3$, Ethyl carbonate			
3.15±6	20	4	8	(49, 124)

* $\partial_{20} = -0.8$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_5H_{11}Br$, Amyl bromide			
6.3±1	10	Audio		(91)
	$C_5H_{11}Br$, Isoamyl bromide			
6.1	25	Audio		(76)
4.70	120.6 B. P.	Audio		(76)
6.1	18	5	8	(41)
	$C_5H_{11}Br$, *tert.*-Amyl bromide			
9.1	18.5	5	8	(41)
	$C_5H_{11}Cl$, Amyl chloride			
6.6±1	11	Audio		(91)
	$C_5H_{11}Cl$, Isoamyl chloride			
6.4±1	18	5	8	(41)
	$C_5H_{11}Cl$, *tert.*-Amyl chloride			
9.5±1	16	Audio		(91)
7.1	18	5	8	(41)
	$C_5H_{11}I$, Isoamyl iodide			
5.6	18.6	5	8	(41)
	$C_5H_{11}I$, *tert.*-Amyl iodide			
6.9	17.3	5	8	(41)
	$C_5H_{11}N$, Piperidine			
5.9±1	20	3.6	8	(164)
	$C_5H_{11}NO$, Methyl propyl ketoxime			
3.3	20	5	8	(41)
	$C_5H_{11}NO_3$, Amyl nitrate			
9.1±2	18	3.6	8	(124)
	C_5H_{12}, Pentane			
1.828	20.3	Audio		(42)
$C_5H_{12}O$, Amyl alcohol; M. P. = −78.5° (*see also* Table 6)				
15.8±2*	20	Audio		(2, 91, 110, 133, 145)
2.40	−189			(38)
2.14	−187			(38)
2.6	−160			(38)
6.5	−140			(38)
12.0	−136			(38)
26.5	−132			(38)
34.4	−130			(38)
43.0	−126			(38)
41.0	−117	1.2	2	(38)
35.5	−117	Audio		(1, 2)
29.1	− 80			(1, 2)
24.8	− 50			(1, 2)
20.9	− 20			(1, 2)
18.3	0			(145)
15.8±2	+ 20			(2, 91, 110, 133, 145)
11.2	60			(145)
14.6	15	2.5	7	(181)
	$C_5H_{12}O$, Dimethyl ethyl carbinol			
11.7	20	Audio		(28)
10.1	50	Audio		(28)
8.9	80	Audio		(28)
8.0	102 B. P.	Audio		(28)
	$C_5H_{12}O$, Isoamyl alcohol			
15.3	23	Audio		(76)
8.87	80	Audio		(28)
5.82	131.6 B. P.	Audio		(28, 76)
5.7	18	3	8	(160)
	$C_5H_{12}S$, Amylmercaptan			
4.7	20	3.6	8	(54, 163)
4.3	30	3.6	8	(54)
	$C_5H_{13}N$, Amylamine			
4.6±1	22	3.6	8	(164)

* $\partial_{20} = -12$ (1, 2, 145).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_6H_3N_3O_6$, 1, 3, 5-Trinitrobenzene			
7.21	127	Audio		(9)
2.2	*ca.* 20	4	8	(9)
	$C_6H_4Br_2$, *m*-Dibromobenzene			
8.81	20	Audio		(9)
4.4	*ca.* 20	4	8	(9)
	$C_6H_4Br_2$, *p*-Dibromobenzene			
4.57	88	Audio		(9)
2.7s		4	8	(9)
	$C_6H_4Cl_2$, *o*-Dichlorobenzene			
7.47	25	1	6	(161.2)
7.50	20	6.7	7	(193.1)
$C_6H_4Cl_2$, *p*-Dichlorobenzene; M. P. = 52.1°				
2.86	53	Audio		(28)
	$C_6H_4N_2O_4$, *m*-Dinitrobenzene			
20.7	90	Audio		(9)
2.85	*ca.* 20	4	8	(9)
	C_6H_5Br, Bromobenzene			
5.40 ±0.1	20	Audio		(17, 42, 91, 191)
5.47	13	6.7	7	(193.1)
5.4±2	20	4	8	(9, 41)
	$\partial_{20} = -1.6$			(17, 191)
	C_6H_5Cl, Chlorobenzene			
5.94	20	Audio		(17, 42)
4.70	100	Audio		(17)
4.20	132.0 B. P.	Audio		(76)
5.44	25	1	6	(161.2)
5.65	13	6.7	7	(193.1)
5.8	20	5	8	(41)
	$\partial_{20} = -2.4$			(17)
	C_6H_5ClO, *o*-Chlorophenol			
8.2	19	5	8	(9)
6.31	25	1	6	(161.2)
	C_6H_5I, Iodobenzene			
4.6	20	5	8	(41)
$C_6H_5NO_2$, Nitrobenzene; M. P. = +8.7°				
36.1±3*	20	Audio		(2, 119, 183, 191)
2.62	−190			(68)
2.54	−170			(68)
2.56	−150			(68)
2.63	−100			(68)
2.97	− 80			(68)
3.15	− 40			(68)
3.40	− 20			(68)
9.9	− 10			(2)
42.1	− 9			(2)
39.7	0			(2)
36.1±3	+ 20			(2, 119, 183, 191)
32.3	40			(92)
26.3	80			(92)
27.0	80			(127)
21.9	120			(92)
18.6	160			(92)
15.9	200			(92)
15.61	210.85 B. P.	Audio		(76)
35.4	20	6	5	(92)
34.3±6	20	4	8	(49, 99, 190)
37.5	20	5	8	(41)

* $\partial_{20} = -18$ (2, 183, 191).

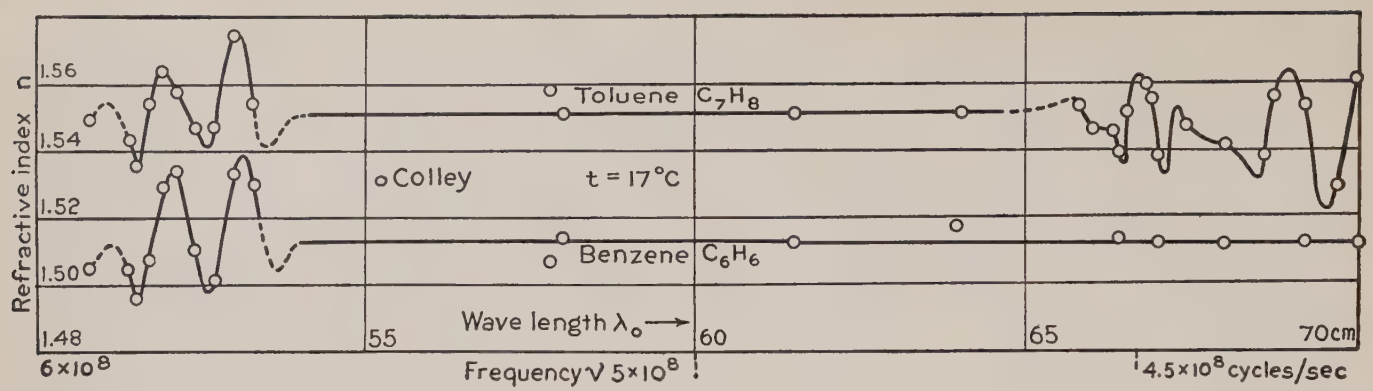

FIG. 1.—Variation of refractive index with wave-length [34].

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
C_6H_6, Benzene; M. P. = 5.5° (*see* Fig. 1)				
2.283±2*	20	Audio		(177, 183, 188)
2.293	−180			(87)
2.310	−120			(87)
2.322	− 80			(87)
2.337	− 40			(87)
2.340	− 20			(87)
2.342	− 10			(87)
2.363	+ 3			(87)
2.345	4			(87)
2.308	5			(75)
2.300	10			(75, 87)
2.296±1	10			(77, 127)
2.282	20			(34, 75, 87, 177, 183, 188)
2.204	60			(75, 87, 177)
2.228±2	60			(77, 127)
2.127	100			(177)
2.049	140			(177)
1.970	180			(177)
2.28	20	6	5	(75)
2.28	20	1; 3	7	(123)
2.281±4	20	4	8	(34, 49, 117)
2.43	19	6	8	(122)
2.57	19	8	8	(122)
2.26	*ca.* 20	3	9	(108)
3.4(?)	*ca.* 20	3.5	9	(111)
2.31	*ca.* 20	4.7	9	(108)
2.33(?)	*ca.* 20	7	9	(108)
3.83(?)	*ca.* 20	7	9	(122)
3.13	*ca.* 20	3.7	10	(109)
3.1	*ca.* 20	5	10	(109)
3.04	*ca.* 20	7.5	10	(109)
C_6H_6BrN, *m*-Bromoaniline				
13.0	19	5	8	(41)
C_6H_6ClN, *m*-Chloroaniline				
13.3±2	16	Audio		(91)
13.3	19	5	8	(41)
C_6H_6O, Phenol; M. P. = +41°				
ca. 15	40	Audio		(140)
2.54	−185			(38)
2.59	−140			(38)
4.33	+ 10	4	8	(49)
9.9±2	48	4	8	(49)

* $\partial_{20} = -0.19$ (75, 77, 87, 127, 145).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
$C_6H_6O_2$, Resorcinol				
3.2±28	22	4	8	(174)
C_6H_7N, Aniline; M. P. = −6.2°				
7.25±5*	20	Audio		(91, 133, 183)
2.92	−178			(38)
2.95	−160			(38)
3.05	−120			(38)
3.48	− 80			(38)
7.78	0			(92, 145)
7.25±5	+ 20			(91, 95, 133, 183)
6.59	50			(145)
6.43	50			(92)
6.22	70			(145)
5.98	70			(92)
5.46	100			(92)
4.71	150			(92)
4.45	170			(92)
4.54	184.5 B. P.			(76)
7.18±7	20	1	6	(95)
7.2±1	20	4	8	(41, 49, 124, 164)
4.36	*ca.* 20	7	9	(125)
C_6H_7N, α-Picoline				
10. 0±2	20	3.6	8	(164)
$C_6H_8N_2$, Phenylhydrazine				
7.15 ±0.21	23	Audio		(183)
5.8	17	4	8	(41, 124)
$C_6H_8O_4$, Methyl acetoneoxalate				
15.4†	67	4	8	(49)
2.38‡	6	4	8	(49)
$C_6H_9ClO_2$, Ethyl 2-chlorocrotonate				
7.67§	20	4	5	(61.1)
4.70‖	20	4	5	(61.1)
$C_6H_{10}O$, Cyclohexanone				
18.2	20	Audio		(147)
$C_6H_{10}O$, Mesityl oxide				
15.4±3	20	4	8	(189)
$C_6H_{10}O_2$, Ethyl crotonate				
5.4±2	20	5	8	(41)

* $\partial_{20} = -2.5$ (92, 145, 183).
† $k' = 0.06$.
‡ $k' = 0.00$.
§ *Cis;* B. P. = 75.3; 76.0° at pressure of 14 mm Hg.
‖ *Trans;* B. P. = 54.0° at pressure of 14 mm Hg.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_6H_{10}O_3$, Propionic anhydride			
18.3±6	16	5	8	(41)
	$C_6H_{10}O_3$, Ethyl acetoacetate			
15.9±2	22	4	8	(49)
	$C_6H_{10}O_4$, Diethyl oxalate			
8.2±1	21	4	8	(49)
	$C_6H_{10}O_4$, Dimethyl succinate			
5.20	19.5 M. P.	Audio		(28)
	$C_6H_{10}S$, Diallyl sulfide			
4.9	*ca.* 20	4	8	(9)
	$C_6H_{11}BrO_2$, Ethyl 1-bromobutyrate			
8.0	20	5	8	(41)
	$C_6H_{11}BrO_2$, Ethyl 1-bromoisobutyrate			
7.9	20	5	8	(41)
	$C_6H_{11}ClO_2$, Isoamyl chloroformate			
7.8	20	5	8	(41)
	$C_6H_{11}N$, Isocapronitrile; slight absorption			
15.7±2	20	3.6	8	(99, 163)
	$C_6H_{11}NS$, Amyl thiocyanate			
17.4±3	20	3.6	8	(54)
	C_6H_{12}, Cyclohexane			
2.052	20	Audio		(28, 147)
2.10	4.5 M. P.	Audio		(28)
	$\partial_{20} = -0.16$			(28)
	C_6H_{12}, α-Hexylene			
2.03	17	Audio		(110)
	$C_6H_{12}O$, Cyclohexanol			
15.0	25	Audio		(147)
	$C_6H_{12}O$, Methyl *tert.*-butyl ketone			
12.4±2	17	4	8	(49)
	$C_6H_{12}O$, Pinacolin			
12.8	17.5	3.6	8	(54)
	$C_6H_{12}O_2$, Caproic acid			
3.22±6	18	5	8	(41)
	$C_6H_{12}O_2$, Amyl formate			
7.7	15	3.8	1	(180)
5.7	19	4	8	(49)
	$k'_{20} = 0.009$	2	8	(35)
	$C_6H_{12}O_2$, *n*-Butyl acetate			
5.14*	+ 19	Audio		(119)
2.41	−195			(89)
2.395	− 77.9			(89)
6.97	− 77.9			(89)
5.54	− 20			(89)
5.34	0			(89)
5.00	+ 20			(89)
5.00	20	4.7	5	(89)
5.1±1	19	4	8	(49)
	$C_6H_{12}O_2$, Ethyl butyrate			
5.19±5	20	Audio		(119, 180)
5.2±1	20	4	8	(49)
$\partial_{20} = -1.0$	20	Audio		(119)
	$C_6H_{12}O_2$, Isobutyl acetate			
5.60±0.1†	20	Audio		(110, 119, 180)
5.32	25	1	6	(161.2)
5.4±1	20	4	8	(49)
	$C_6H_{12}O_2$, Methyl valerate			
4.3	19	5	8	(41)
	$C_6H_{12}O_2$, Propyl propionate			
4.7	20	5	8	(41)

* $\partial_{20} = -1.6$ (89, 119).
† $\partial_{20} = -1.6$ (119).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_6H_{12}O_3$, Paraldehyde			
14.5±1	20	Audio		(76, 191)
12.2±2	50	Audio		(191)
6.29	128.0 B. P.	Audio		(76)
ca. 12.0	20	4	8	(189)
	$C_6H_{13}I$, Hexyl iodide			
6.6	20	5	8	(41)
	C_6H_{14}, Hexane			
1.874*	20	Audio		(110, 133, 147, 188)
	$C_6H_{14}O_2$, Acetal			
3.45±5	24	Audio		(191)
3.59±9	21	4	8	(49)
	$C_6H_{14}O_2$, Pinacone			
7.4	24	3.6	8	(124)
	$C_6H_{14}O_6$, Mannitol			
3.0±2*s*	22	4	8	(174)
	$C_6H_{15}N$, Dipropylamine			
2.9	20	3.6	8	(124, 164)
	$C_6H_{15}N$, Triethylamine			
3.15	21	Audio		(191)
	C_7H_5ClO, Benzoyl chloride			
19.0±4	24	3 6	8	(124)
	$C_7H_5Cl_3$, Benzotrichloride			
7.4	20	3.6	8	(124)
6.4	20	5	8	(41)
	C_7H_5N, Benzonitrile			
26.5	20	Audio		(191)
28.8	0	Audio		(191)
26.5	20	4	8	(49, 163, 190)
	C_7H_5NO, Phenyl isocyanate			
5.7	17	3.6	8	(54)
8.9	20	3.6	8	(124)
	C_7H_5NS, Phenyl isothiocyanate			
10.7±5	20	4	8	(124, 189)
	$C_7H_6Cl_2$, Benzal chloride			
6.9	20	5	8	(41)
	$C_7H_6N_2O_3$, *anti-m*-Nitrobenzaldoxime			
48.1	120	Audio		(9)
2.58*s*		4	8	(9)
	$C_7H_6N_2O_3$, *syn-m*-Nitrobenzaldoxime			
59.3	117.5	Audio		(9)
2.78*s*		4	8	(9)
	C_7H_6O, Benzaldehyde			
18.0	20	Audio		(191)
20.0	0	Audio		(191)
17.5±3	20	4	8	(49)
14.5	15	2.5	7	(181)
14.1±3	20	3.6	8	(124)
	$C_7H_6O_2$, Salicylaldehyde			
13.9	20	4	8	(189)
17.9	17	4	8	(49)
19.2	15	2.5	7	(181)
	C_7H_7Br, *o*-Bromotoluene			
5.32	20	5	8	(41)
	C_7H_7Br, *p*-Bromotoluene			
5.15	28 M. P.	Audio		(28)
	C_7H_7Cl, Benzyl chloride			
7.0±2	13	Audio		(91)
6.4	20	5	8	(41)
	C_7H_7Cl, *o*-Chlorotoluene			
4.73	20	5	8	(41)

* $\partial_t = -0.11$; $(-80\ t\ +12)$ (127).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_7H_7Cl, *m*-Chlorotoluene			
5.4	16	Audio		(91)
5.55	20	5	8	(41)
	C_7H_7Cl, *p*-Chlorotoluene			
6.40	10	Audio		(28)
6.19	20	Audio		(28)
5.94	30	Audio		(28)
6.45	7.4 M. P.			(28)
6.21	20	5	8	(41)
	C_7H_7I, *p*-Iodotoluene			
4.46	35 M. P.	Audio		(28)
	C_7H_7NO, *anti*-Benzaldoxime			
3.85±4	20	Audio		(119)
3.40±6	20	4	8	(49)
3.55	20	5	8	(41)
	C_7H_7NO, Formanilide			
20.5*l*				(189)
3.05*s*		4	8	(9)
	$C_7H_7NO_2$, *o*-Nitrotoluene			
27.42±5*	20	Audio		(183)
25.8	20	2.5	7	(181)
20.3	18	3.6	8	(124)
26.0	20	5	8	(41)
11.82	222.3 B. P.	Audio		(76)
	$C_7H_7NO_2$, *m*-Nitrotoluene			
23.8	20	6.7	7	(193.1)
23.6	20	5	8	(41)
	$C_7H_7NO_2$, *p*-Nitrotoluene			
18.7	52 M. P.	Audio		(28)
	$C_7H_7NO_3$, *m*-Nitrobenzyl alcohol			
22.0±5	20	5	8	(41)
	$C_7H_7NO_3$, Nitroanisole			
24.2	20	3.6	8	(54)
	C_7H_8, Toluene; M. P. = −94.5° (*see* Fig. 1)			
2.387±5†	20	Audio		(17, 42, 110, 145, 177, 111.1)
2.520	−186			(87)
2.526	−140			(87)
2.530	−114			(87)
2.600	−100			(87)
2.632	− 94			(87)
2.61	− 80			(87)
2.57	− 60			(87)
2.485	− 20			(17, 87)
2.435	0			(17, 87)
2.387±5	+ 20			(17, 42, 110, 145, 177)
2.250	80			(87, 177)
2.165	120			(87, 177)
2.040	180			(87, 177)
2.39	20	6	4	(86)
2.388	20	6	5	(87)
2.37±4	20	2.5	7	(181)
2.402±4	20	5	8	(34, 41, 117)
	C_7H_8O, Benzyl alcohol			
15.9	0	Audio		(191)
13.0	20	Audio		(191)
10.3	50	Audio		(191)
10.8±2‡	21	4	8	(48)

* $\partial_{20} = -15$ (183).
† $\partial_{20} = -0.23$ (87, 145, 177).
‡ $k' = 0.20$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_7H_8O, *o*-Cresol			
ca. 8	40	Audio		(140)
5.8±1	24	3.6	8	(124)
	C_7H_8O, *m*-Cresol			
ca. 13	40	Audio		(140)
5.0±1	24	3.6	8	(124)
	C_7H_8O, *p*-Cresol			
ca. 13	40	Audio		(140)
5.6±1	24	3.6	8	(124)
	C_7H_8O, Anisole			
4.7	5	Audio		(191)
4.35±5	20	Audio		(140, 191)
4.0	50	Audio		(191)
3.62±7	18	3.6	8	(124)
	$C_7H_8O_2$, Guaiacol (supercooled)			
11.7*l*	<32	5	8	(41)
	C_7H_9N, Benzylamine			
5.6	0	Audio		(191)
4.6	20	Audio		(191)
4.3	50	Audio		(191)
5.2	20	5	8	(41)
	C_7H_9N, Methylaniline			
7.98	0	Audio		(191)
6.01	20	Audio		(191)
5.9	20	3.6	8	(124, 164)
	C_7H_9N, *o*-Toluidine			
6.4	26	Audio		(76)
4.00	199.7 B. P.	Audio		(76)
6.0	20	4	8	(41, 164)
	C_7H_9N, *m*-Toluidine			
6.0	20	4	8	(41, 164)
	C_7H_9N, *p*-Toluidine; M. P. = 43.7°			
5.48	44	Audio		(28)
3.0±2	22	4	8	(174)
	$C_7H_{10}N_2$, *asym.*-Methylphenylhydrazine			
7.3	19	5	8	(41)
	$C_7H_{10}O$, 1-Methyl-5-ketocyclohexylene			
24.32	20			(154)
	$C_7H_{10}O_4$, Ethyl acetoneoxalate			
16 ± 1	19	Audio		(119)
16.7±3*	19	4	8	(49)
	$C_7H_{10}O_4$, Ethyl hydroxymethyleneacetoacetate			
8.12	21	Audio		(119)
7.8±1†	21	4	8	(49)
	$C_7H_{12}O_3$, Ethyl levulinate			
12.1±2	21	4	8	(49)
	$C_7H_{12}O_4$, Diethyl malonate			
7.9±2	21	4	8	(49)
8.4±2	21	5	8	(41)
	$C_7H_{13}ClO_2$, Isoamyl chloroacetate			
7.8	20	5	8	(41)
	$C_7H_{14}O$, Dipropyl ketone			
12.6±2	17	1; 40	7	(49, 181)
	$C_7H_{14}O_2$, Amyl acetate			
5.07±9‡	20	Audio		(110, 119, 180)
4.62	25	1	6	(161.2)
4.88 ±0.1	20	4	8	(49)
	$C_7H_{14}O_2$, Ethyl valerate			
4.81§	20	Audio		(119, 180)
4.77 ± 9	20	4	8	(49)

* $k' = 0.09$. † $k' = 0.08$. ‡ $\partial_{20} = -1.2$ (119). § $\partial_{20} = -1.0$ (119).

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_7H_{14}O_2$, Propyl butyrate			
4.3	20	5	8	(41)
	C_7H_{16}, Heptane			
1.971	20	Audio		(42, 147)
	$C_7H_{16}O$, Heptyl alcohol			
6.73	21	Audio		(119)
4.2±1*	21	4	8	(49)
	$C_7H_{16}O$, Ethyl amyl ether			
3.565	23	Audio		(42)
4.02	20	5	8	(41)
	$C_8H_6O_2$, Phthalide			
36	75	4	8	(49)
4*s*	20	4	8	(49)
	C_8H_7N, Benzyl cyanide			
20.10	0	Audio		(191)
18.32	20	Audio		(191)
16.84	50	Audio		(191)
8.5	233.5 B. P.	Audio		(76)
15.2	20	4	8	(49, 163)
16.7	20	4	8	(189)
	C_8H_7N, *o*-Tolunitrile			
18.8±4	23	3.6	8	(163)
	C_8H_7NO, Mandelic nitrile			
18.1±3†	23	3.6	8	(164)
	C_8H_8O, Phenylacetaldehyde			
4.87±9	20	4	8	(49)
	C_8H_8O, Acetophenone			
18.6 ± 1	15	Audio		(191)
18.3±1	20	Audio		(183, 191)
15.9±2	50	Audio		(191)
8.64	202.0 B. P.	Audio		(76)
16.2	15	2.5	7	(181)
15.8±3	20	4	8	(49)
	$C_8H_8O_2$, *p*-Anisaldehyde			
10.38	248.0 B. P.	Audio		(76)
ca. 22.3	22	Audio		(76)
ca. 15.8	20	4	8	(189)
	$C_8H_8O_2$, Phenylacetic acid			
ca. 4	85	4	8	(49)
ca. 3.2	20	4	8	(49)
	$C_8H_8O_2$, Methyl benzoate			
6.9±2‡	20	Audio		(119, 180)
6.6±2	20	4	8	(49, 124)
	$C_8H_8O_2$, Phenyl acetate			
5.35±5§	20	Audio		(119)
5.15	25	1	6	(161.2)
5.38 ±0.1	20	4	8	(49)
6.4	24	3.6	8	(124)
$k' = 0.012$	20	2	8	(35)
	$C_8H_8O_3$, Methyl salicylate			
9.0±2‖	20	4	8	(41, 49)
	C_8H_9NO, Acetanilide			
19.5*l*				(189)
2.9±1*s*	22			(9, 174)
	$C_8H_9NO_2$, *anti-p*-Anisaldoxime			
9.2*s*	63	Audio		(9)
2.7*s*		4	8	(9)

* $k' = 0.31$.
† $k' = 0.045$.
‡ $\partial_{20} = -1.2$ (119, 180).
§ $\partial_{20} = -0.75$ (119).
‖ $k' = 0.07$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_8H_9NO_2$, *syn-p*-Anisaldoxime			
10.9	130	Audio		(9)
2.7*s*		4	8	(9)
	C_8H_{10}, Ethylbenzene			
2.479	20	Audio		(110, 133, 147)
	C_8H_{10}, *o*-Xylene			
2.58	17	Audio		(110, 133)
2.58±5	17	4	8	(41, 49)
	C_8H_{10}, *m*-Xylene; M. P. = −53.6°			
2.374±2*	+ 20	Audio		(42, 133, 147, 177, 183)
2.400	−186			(87)
2.550†	− 80			(87)
2.400	− 70			(87)
2.600‡	− 60			(87)
2.453	− 52			(87)
2.530	− 50			(87)
2.566	− 48			(87)
2.540	− 40			(87)
2.473	− 20			(87)
2.420	0			(87)
2.374	+ 20			(42, 133, 147, 177, 183)
2.257	80			(177)
2.178	120			(177)
2.058	180			(177)
2.392	20	6	5	(87)
2.35	20	5	7	(8)
2.37±3	20	4	8	(49)
	C_8H_{10}, *p*-Xylene			
2.259	17	Audio		(110, 133)
2.21	17	4	8	(41, 49)
	$C_8H_{10}O$, *o*-Tolyl methyl ether			
3.57	20	Audio		(140)
3.4±1	20	4	8	(41, 124)
	$C_8H_{10}O$, *m*-Tolyl methyl ether			
4.08	20	Audio		(140)
3.6	20	5	8	(41)
	$C_8H_{10}O$, *p*-Tolyl methyl ether			
4.03	20	Audio		(140)
3.6	20	5	8	(41)
	$C_8H_{10}O$, Phenetole			
4.56±9	21	3.6	8	(124)
	$C_8H_{10}O$, 1, 3, 4-Xylenol			
4.8	17	5	8	(41)
	$C_8H_{10}O_2$, Creosol			
10.6	17	Audio		(119)
11.8	15	2.5	7	(181)
6‡	17	4	8	(49)
	$C_8H_{10}O_2$, Veratrol			
4.54	22.5 M. P.	Audio		(28)
	$C_8H_{11}N$, Benzylmethylamine			
4.4	19	5	8	(41)
	$C_8H_{11}N$, Dimethylaniline			
4.84	0	Audio		(191)
4.48	20	Audio		(191)
3.93	50	Audio		(191)
5.1	20	3.6	8	(124, 164)

* $\partial_{20} = -0.19 \pm 1$ (87, 133, 177, 183).
† Supercooled.
‡ $k' = 0.28$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_8H_{11}N$, Ethylaniline			
6.3	0	Audio		(191)
5.9	20	Audio		(191)
5.76	20	6.7	7	(193.1)
5.4	19	5	8	(41)
	$C_8H_{11}N$, *m*-Xylidine			
5.0±1	20	4	8	(41, 124, 164)
	$C_8H_{11}NO$, Phenetidine			
7.3±2	21	3.6	8	(124)
	$C_8H_{12}O_5$, Diethyl oxaloacetate			
6.1±1*	19	4	8	(49)
	$C_8H_{12}O_5$, Ethyl hydroxymethylenemalonate			
6.6±1†	22	4	8	(49)
	$C_8H_{14}O_3$, Butyric anhydride			
12.9	20	5	8	(41)
	$C_8H_{14}O_3$, Isobutyric anhydride			
13.9±3	20	4	8	(189)
17.8	17	5	8	(41)
	$C_8H_{14}O_5$, Diethyl *dl*-malate			
10.2±2‡	18	4	8	(49)
	$C_8H_{14}O_5$, Diethyl *l*-malate			
9.5±2	20	4	8	(189)
	$C_8H_{14}O_6$, Diethyl tartrate			
4.59±9	20	5	8	(176)
	$C_8H_{14}O_6$, Diethyl racemate			
4.59±9	20	5	8	(176)
	C_8H_{16}, Octylene			
2.21	12	Audio		(110)
4.15	18.5	5	8	(41)
	$C_8H_{16}O$,Methyl hexyl ketone			
10.4	15	2.5	7	(181)
10.7±2	17	4	8	(49)
	$C_8H_{16}O_2$, Caprylic acid			
3.26	18.3	5	8	(41)
	$C_8H_{16}O_2$, Isoamyl propionate			
4.25	19.5	5	8	(41)
	$C_8H_{16}O_2$, Isobutyl butyrate			
4.05	20	5	8	(41)
	$C_8H_{16}O_2$, Propyl valerate			
4.00	18.8	5	8	(41)
	$C_8H_{17}I$, *n*-Octyl iodide			
4.92	20	5	8	(41)
	$C_8H_{17}I$, *sec.*-Octyl iodide			
5.87	20	5	8	(41)
	C_8H_{18}, Octane			
1.960	20	Audio		(110, 133, 147)
	C_8H_{18}, 2, 2, 3-Trimethylpentane			
1.959	20	Audio		(147)
	$C_8H_{18}O$, Octyl alcohol			
3.4	18	3	8	(160)
	$C_8H_{19}N$, Diisobutylamine			
2.70±5	22	3.6	8	(164)
	$C_8H_{20}O_4Si$, Tetraethyl silicate			
4.10	*ca.* 20	3.6	8	(124)
	C_9H_7N, Quinoline; M. P. = −22.6°			
9.00	+ 25	Audio		(76, 183)
2.67	−180			(38)
2.9	−150			(38)
11.7	−100			(38)
9.0	+ 25	Audio		(41, 76, 124, 163, 183)

* $k' = 0.25$. † $k' = 0.09$. ‡ $k' = 0.25$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_9H_7N.—(*Continued*)			
5.05	238 B. P.	Audio		(76)
8.9±1	21	4	8	(41, 124, 163)
	C_9H_7NO, Hydroxymethylenebenzyl cyanide			
5(?)*	180	4	8	(49)
6(?)s	20	4	8	(49)
	$C_9H_{10}O_2$, Benzyl acetate			
5.05	21.2	5	8	(41)
	$C_9H_{10}O_2$, Ethyl benzoate			
6.2±1†	20	Audio		(119, 180)
6.0±2	20	4	8	(49, 124)
$k' = 0.018$	20	2	8	(35)
	$C_9H_{10}O_2$, Methyl *p*-toluate			
4.34	33	Audio		(28)
	$C_9H_{10}O_3$, Ethyl salicylate			
8.6	21	Audio		(119)
8.4±2‡	21	4	8	(41, 49)
	$C_9H_{10}O_3$, Methyl *o*-methoxybenzoate			
7.8±1‡	21	4	8	(49)
	C_9H_{12}, Mesitylene			
2.353	20	Audio		(110, 147)
	C_9H_{12}, Cumene			
2.397	20	Audio		(110, 133, 147, 182)
2.42	18	4	8	(49)
	C_9H_{12}, Psuedocumene			
2.43	16	Audio		(110, 133)
	C_9H_{12}, Propylbenzene			
2.361	20	Audio		(110, 133, 147)
	$C_9H_{12}O$, Ethyl benzyl ether			
3.87±6	20	5	8	(41)
	$C_9H_{13}N$, Benzylethylamine			
4.3	20	5	8	(41)
	$C_9H_{13}N$, *o*-Dimethyltoluidine			
3.37±7	20	5	8	(41)
	$C_9H_{13}N$, *p*-Dimethyltoluidine			
3.95±8	20	5	8	(41)
	$C_9H_{13}NO_3S$, *p*-Trimethylsulfanilic acid			
ca. 94	12.5	Audio		(101)
ca. 89	18	4	8	(101)
	$C_9H_{14}O_5$, Diethyl oxalopropionate			
9.1±2§	19	4	8	(49)
	$C_9H_{14}O_6$, Glyceryl triacetate			
6.0±1	21	5	8	(41)
	$C_9H_{18}O_2$, Isoamyl butyrate			
3.95±8	20	5	8	(41)
	$C_9H_{18}O_2$, Isobutyl valerate			
3.85±8	19	5	8	(41)
	C_9H_{20}, 2, 2′-Dimethylheptane			
1.89	20	Audio		(147)
	C_9H_{20}, 2, 4-Dimethylheptane			
1.89	20	Audio		(147)
	C_9H_{20}, 2, 5-Dimethylheptane			
1.99	20	Audio		(147)
	C_9H_{20}, 2-Methyloctane			
1.965	20	Audio		(147)
	C_9H_{20}, 4-Methyloctane			
1.965	20	Audio		(147)

* $k' = 0.30$.
† $\partial_{20} = -0.9$ (119, 180).
‡ $k' = 0.07$.
§ $k' = 0.19$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	C_9H_{20}, Nonane			
1.965	20	Audio		(147)
	$C_{10}H_7Br$, 1-Bromonaphthalene			
5.17±5	19	Audio		(183)
5.00±5	22.7	Audio		(42)
4.85±5*	19	4	8	(41, 49)
	$C_{10}H_8$, Naphthalene			
2.52±8†	20	4	8	(81, 174)
2.51	15			(81)
2.40	40			(81)
2.30	60			(81)
2.19	80 M. P.			(81)
2.30	100			(81)
2.43	120			(81)
2.61	150			(81)
2.64	180			(81)
2.23	80 M. P.	4	8	(81)
3.27	80.5 M. P.	Audio		(28)
	$C_{10}H_{10}O_2$, Benzoylacetone			
15.7(?)*l*‡	80	4	8	(49)
2.8(?)*s*	20	4	8	(49)
	$C_{10}H_{10}O_2$, Safrol			
3.12±6	21	4	8	(49)
2.57	18	3.6	8	(124)
	$C_{10}H_{10}O_2$, Isosafrol			
3.40±7	21	4	8	(49)
	$C_{10}H_{12}O$, Cumicaldehyde			
10.7	15	2.5	7	(181)
	$C_{10}H_{12}O_2$, Phenylethyl acetate			
4.5±2	15	Audio		(171)
	$C_{10}H_{12}O_2$, Ethyl phenylacetate			
5.4±1	21	4	8	(49)
	$C_{10}H_{12}O_2$, Eugenol; some absorption			
6.1±1	18	3.6	8	(124)
	$C_{10}H_{14}$, *p*-Cymene			
2.26	17	Audio		(76, 110, 133)
2.27	176.5 B. P.	Audio		(76)
2.43	18	3.6	8	(124)
	$C_{10}H_{14}$, Isobutylbenzene			
2.36	17	Audio		(110, 133)
	$C_{10}H_{14}$, *tert.*-Butylbenzene			
2.381	20	Audio		(147)
2.0	20	5	8	(41)
	$C_{10}H_{14}O$, Carvol			
11.2±2	18	3.6	8	(124)
	$C_{10}H_{14}O_3$, "Hagemann's ester"			
18.0±4§	20	4	8	(49)
10.6±2‖	20	4	8	(49)
	$C_{10}H_{16}$, Terpinene			
2.7	21	3.6	8	(124)
	$C_{10}H_{16}$, *d*-Camphene			
2.75	20	5	8	(176)
	$C_{10}H_{16}$, *l*-Camphene			
2.75	20	5	8	(176)
	$C_{10}H_{16}$, *dl*-Camphene			
2.75	20	5	8	(176)
	$C_{10}H_{16}$, Dipentene			
2.30	20	5	8	(176)
3.2	21	3.6	8	(124)
	$C_{10}H_{16}$, *d*-Limonene			
2.36	20	5	8	(176)

* $k' = 0.05$. † $\partial_{20} = -0.7$ (81, 174). ‡ Enol form.
§ $k' = 0.09$, keto form.
‖ $k' = 0.27$, enol form.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_{10}H_{16}$, *d*-Pinene			
2.60	20	5	8	(176)
	$C_{10}H_{16}$, *l*-Pinene			
2.70	20	5	8	(176)
	$C_{10}H_{16}$, *dl*-Pinene			
2.75	20	5	8	(176)
	$C_{10}H_{16}O$, Dihydrocarvone			
8.7±2	19	4	8	(49)
	$C_{10}H_{16}O$, Carvenone (?)			
19.3±2	20	Audio		(119)
18.4±4*	20	4	8	(49)
	$C_{10}H_{16}O$, Pulegone			
9.7±2	19	4	8	(49)
	$C_{10}H_{18}O$, Menthone			
9.6	20	5	8	(41)
8.9	18	3.6	8	(124)
	$C_{10}H_{18}O$, Terpineol			
3.7	21	3.6	8	(124)
2.80±5	20	4	8	(49)
	$C_{10}H_{18}O_2$, Acetylmethyl hexyl ketone			
27.9±5	19	3.6	8	(54)
	$C_{10}H_{20}$, Decylene			
2.27	17	Audio		(110)
	$C_{10}H_{20}$, Diisoamylene			
2.43	17	Audio		(133)
	$C_{10}H_{20}O_2$, Isoamyl valerate			
3.62±7	19	5	8	(41)
	$C_{10}H_{22}$, Decane			
1.953	20	Audio		(110, 147)
	$C_{10}H_{22}$, Di(iso?)amyl			
1.99	17	Audio		(133)
	$C_{10}H_{22}O$, Amyl ether			
3.14±6	16	4	8	(49)
	$C_{10}H_{23}N$, Diamylamine			
2.57±5	18	3.6	8	(124)
	$C_{11}H_7N$, α-Naphthonitrile			
16.3±3*l*	70	3.6	8	(164)
18.4±4*l*	40	3.6	8	(164)
19.6±4*l*	22	3.6	8	(164)
6.4±1*s*	21	3.6	8	(164)
	$C_{11}H_7N$, β-Naphthonitrile			
17.2±3	70	3.6	8	(164)
4.3	22	3.6	8	(164)
	$C_{11}H_{10}O_4$, Methyl acetophenoneoxalate; double enol form			
13.2(?) †	70	4	8	(49)
2.8(?)*s*	18	4	8	(49)
	$C_{11}H_{12}O_2$, Ethyl cinnamate			
6.62±6	19	Audio		(119)
5.36 ±0.1‡	19	4	8	(49)
	$C_{11}H_{12}O_3$, Ethyl benzoylacetate			
12.8 ±1	20	Audio		(119)
ca. 9.4§	20	4	8	(189)
14.6‖	20	4	8	(49)
ca. 11	65	4	8	(49)
	$C_{11}H_{12}O_3$, Ethyl formylphenylacetate			
3.0	20	4	8	(49)
	$C_{11}H_{12}O_3$, Ethyl hydroxymethylenephenylacetate			
5.0±1¶	20	4	8	(49)

* $k' = 0.12$.
† $k' = 0.14$.
‡ $k' = 0.08$.
§ Absorption.
‖ $k' = 0.24$.
¶ $k' = 0.27$.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
$C_{11}H_{14}O_2$, Isobutyl benzoate				
5.9	20	3.8	1	(180)
5.51±5*	20	Audio		(119)
5.52 ±0.1	20	4	8	(49)
4.97 ±0.1	20	5	8	(41)
k' = 0.028	20	2	8	(35)
$C_{11}H_{14}O_3$, Ethyl *o*-ethoxybenzoate				
7.1±2†	21	4	8	(49)
$C_{11}H_{16}O_2$, 3-Hydroxymethylenecamphor				
12.6(?) §	97	4	8	(49)
5.2(?)*s*§	30	4	8	(49)
$C_{11}H_{18}O_6$, Triethyl 1, 1, 2-ethanetricarboxylate				
6.58 ±0.13‖	19	4	8	(49)
$C_{12}H_{10}$, Acenaphthene				
3.0±2	21	4	8	(174)
$C_{12}H_{10}O$, Diphenyl ether (supercooled)				
3.9*l*	<28	5	8	(41)
$C_{12}H_{11}N$, Diphenylamine				
3.35	52 M. P.	Audio		(28)
$C_{12}H_{12}O$, α-Naphthyl ethyl ether				
3.25	19.4	5	8	(41)
$C_{12}H_{12}O_4$, Ethyl acetophenoneoxalate				
8.0(?)¶	46	4	8	(49)
3.3(?)*s***	18	4	8	(49)
$C_{12}H_{16}O_2$, Amyl benzoate				
5.15±5††	20	Audio		(119, 180)
4.90 ±0.1‡‡	20	4	8	(49, 124)
k' = 0.023	20	2	8	(35)
$C_{12}H_{16}O_3$, Isoamyl salicylate				
5.4±1	20	5	8	(41)
$C_{12}H_{16}O_6$, Diethyl succinosuccinate				
3(?)*l*	130	4	8	(49)
2.5(?)*s*	19	4	8	(49)
$C_{12}H_{18}O_6$, Triethyl aconitate				
6.46±6§§	20	Audio		(119)
5.50±5	70	Audio		(119)
5.75 ±0.11‖‖	20	4	8	(49)
$C_{12}H_{18}O_6$, Triethyl isoaconitate				
7.2±1¶¶	20	4	8	(49)
4.9±1***	20	4	8	(49)
$C_{13}H_{10}O$, Benzophenone				
3.1*s*	25.5	Audio		(191)
13.3*l*	20	Audio		(191)
12.4†††	40	Audio		(191)
11.4†††	60	Audio		(191)
$C_{13}H_{12}$, Diphenylmethane				
2.6*l*	27	4	8	(49)
2.7*s*	17	4	8	(49, 124)
$C_{13}H_{14}O_4$, Ethyl benzoylacetoacetate				
11.8±1	21	Audio		(119)
8.6±2‡‡‡	21	4	8	(49)

* ∂_{20} = −1.2 (119).
† k' = 0.06.
§ k' = 0.05.
‖ k' = 0.08.
¶ Double enol form, k' = 0.24.
** k' < 0.02.
†† ∂_{20} = −0.7 (119, 180).
‡‡ k' = 0.02.
§§ ∂_{20} = −1.6.
‖‖ k' = 0.19.
¶¶ Enol form, k' = 0.11.
*** Keto form, k' < 0.2.
††† Either stable or metastable forms.
‡‡‡ γ enol form; k' = 0.26.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
$C_{14}H_{10}$, Phenanthrene; M. P. = 99°				
2.80	20	4	8	(81, 174)
2.79	15			(81)
2.84	40			(81)
2.96	80			(81)
3.13	100			(81)
3.22	110			(81)
3.10	150			(81)
2.96	190			(81)
∂_{20} = +0.2				(81, 174)
$C_{14}H_{10}O_2$, Benzil				
4.20±4	95	Audio		(28)
$C_{14}H_{12}O_2$, Benzyl benzoate				
4.85 ±0.1	20	5	8	(41)
$C_{14}H_{12}O_3$, Benzyl salicylate				
4.1	20	5	8	(41)
$C_{14}H_{14}N_2O_3$, *p*-Azoxyanisole				
4.2	130	Audio		(3)
2.3*s*	50			(3)
2.3*s*	80			(3)
2.5*s*	85			(3)
3.8*s*	90			(3)
4.3*l**	100			(3)
4.2*l**	120			(3)
4.1*l*†	135			(3)
4.0*l*†	150			(3)
6.9	130	4	5	(94)
$C_{14}H_{15}N$, Dibenzylamine				
3.62±7	20	3.6	8	(124, 164)
$C_{14}H_{16}O_4$, Diethyl benzalmalonate				
7.96±8	0	Audio		(119)
7.63	20	Audio		(119)
6.82	50	Audio		(119)
5.88	70	Audio		(119)
4.4(?)‡	20	4	8	(49)
$C_{15}H_{22}O_8$, Tetraethyl propylene-1, 1, 3, 3-tetracarboxylate				
6.9±2§	19	4	8	(49)
$C_{15}H_{24}O_8$, Tetraethyl propane-1, 1, 3, 3-tetracarboxylate				
6.3±2‖	19	4	8	(49)
$C_{15}H_{24}O_8$, Tetraethyl propane-1, 2, 2, 3-tetracarboxylate				
5.2±1¶	19	4	8	(49)
$C_{16}H_{18}N_2O_3$, *p*-Azoxyphenetole				
6.8	150	4	5	(94)
$C_{16}H_{33}I$, Cetyl iodide				
3.37±6	20	5	8	(41)
$C_{17}H_{21}NO_4$, *d*-Cocaine				
3.10±4	20	5	8	(176)
$C_{17}H_{21}NO_4$, *l*-Cocaine				
3.16±4	20	5	8	(176)
$C_{17}H_{26}O_8$, Tetraethyl α-amylene-1, 1, 3, 3-tetracarboxylate				
4.4±1**	19	4	8	(49)
$C_{17}H_{28}O_8$, Tetraethyl pentane-1, 1, 3, 3-tetracarboxylate				
4.8±1††	19	4	8	(49)
$C_{17}H_{28}O_8$, Tetraethyl pentane-2, 2, 4, 4-tetracarboxylate				
4.2±1‡‡	21	4	8	(49)
$C_{18}H_{34}O_2$, Oleic acid				
2.45 ±0.1	20	4	8	(41, 98)

*Turbid.
† Homogeneous.
‡ k' = 0.15.
§ k' = 0.16.
‖ k' = 0.10.
¶ k' = 0.17.
** k' = 0.03.
†† k' = 0.10.
‡‡ k' = 0.08.

TABLE 4.—(*Continued*)

ϵ	t	A	n	Lit.
	$C_{18}H_{33}O_2Na$, Sodium oleate			
2.75±8*s*	20	4	8	(98)
2.83±8*l*	M. P.	4	8	(98)
	$(C_{18}H_{33}O_2)_2Cu$, Copper oleate			
2.80±8*s*	20	4	8	(98)
2.80±8*l*	M. P.	4	8	(98)
	$(C_{18}H_{33}O_2)_3Fe$, Ferric oleate			
2.68±8	20	4	8	(98)
	$(C_{18}H_{33}O_2)_3Al$, Aluminium oleate			
2.40±8	20	4	8	(98)
	$(C_{18}H_{33}O_2)_2Pb$, Lead oleate			
3.27 ±0.1*s*	18	4	8	(98)
3.70 ±0.1*l*	M. P.	4	8	(98)
	$C_{20}H_{34}O_2$, Camphorpinacone			
3.65		4	8	(9)
	$C_{22}H_{42}O_3$, Isobutyl ricinoleate			
4.7	21	Audio		(191)
$C_{24}H_{34}O_8$, Tetraethyl hexane-1-phenyl-2, 2, 4, 4-tetracarboxylate				
5.9(?)*	20	4	8	(49)
$C_{29}H_{36}O_8$, Tetraethyl pentane-1, 5-diphenyl-2, 2, 4, 4-tetracarboxylate				
2.7*	20	4	8	(49)

*$k' < 0.02$.

TABLE 5.—DIELECTRIC CONSTANT OF GLYCEROL ($C_3H_8O_3$)
See also Table 6

Melts at 17°C. (*a*) = state of purity is unknown (68); (*b*), (*c*), and (*e*) = 98% pure (75); (*d*) = carefully purified (92); (*f*) = pure (20). Frequency = $A \times 10^n$ cycle/sec; t = centigrade temperature, °C; for other symbols, *see* p. 82.

A	1.2	3	4.5	6	7.5	2.2
n	2	5	5	5	5	8
Purity	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)
t	Values of ϵ					
−185	3.21					
−140	3.3					2.8
−100	4.2					2.8
− 80	20					2.8
− 70	46					2.8
− 60	56.5					2.8
− 30		36.5	32.5		22	3.0
− 26		44.5	39		35	3.0
− 20		50.7	48		45	3.0
− 15		50.7	50		48.4	3.1
− 10		49.8	49.8		49.0	3.2
0		47.2	47.2		47.2	3.7
+ 20		43.0	43.0	45.8*	43.0*	14.0
40		39.2	39.2	41.2	39.2	33.0
60		35.8	35.8	37.5	35.8	35.0
80		32.8	32.8	34.8	32.8	32.3
100		30.2	30.2	32.5	30.2	30.2
120				30.7		29.0
140				29.0		28.0
200						25.8

A	n	t	ϵ	k'	Lit.
7.5	5	20	43.0		(75)
1.3	8	15	36.2±1.2	0.27	(44, 46)
4	8	15	19.0±6	0.50	(44, 46)
4	8	20	16.5±6	0.42	(48, 49)
7	9	15	15±2		(125)

* $\partial_{20} = -21 \pm 2$.

TABLE 6.—DISPERSION AND ABSORPTION DATA: ORGANIC COMPOUNDS AND SOLUTIONS

For no organic compound, other than those in this table, are data available for the variation of n and of nk' over a wide range of frequency (ν), but data for one or two values of ν are available for a number of other substances. The values of k' for these substances are given in Table 4.

n = index of refraction, k' = index of absorption, λ_0 = wavelength in a vacuum. If E_x = energy at x of a train of plane waves travelling in the direction of axis of x, then $E_x = E_0 e^{-4\pi nk'x/\lambda_0}$, $\nu = A \times 10^s$. Unit of ν = 1 cycle/sec; of λ_0 = 1 cm; t = centigrade temperature, °C.

CH_4O, Methyl alcohol

n	nk'	t	A	s	λ_0	Lit.
5.65	0.32	18	3.35	8	90	(143, 151)
5.70±5		18	4	8	75	(44, 143)
	0.37±1	18	4	8	75	(11, 48, 143, 151, 196)
	0.48	9	4	8		(11)
	0.33	21	4	8		(11)
	0.36	18	5	8	60	(151)
5.65	0.48	18	5	8	60	(143)
	0.40	18	6	8	50	(151)
5.65	0.66	18	6	8	50	(143)
5.70	1.32	18	7.5	8	40	(143)
6.05	2.33	18	9	8	33	(143)
3.8	1.45	17	5	9	5.7	(53)
5.4			6.7	9	4.5	(125)
3.6	1.38	18	8	9	3.7	(53)
2.8	0.80	17	1.7	10	1.75	(53)

C_2H_6O, Ethyl alcohol (99.5%); *see* Fig. 2

5.17			3.3	7	900	(198)
5.20		18	5	7	600	(32)
			1	8	300	
5.24		18	1.16	8	259	(32)
4.92±5		18	1.4	8	220	(44)
	0.79	18.7	3	8	100	(151)
4.51±6	0.75±5	19	3.5	8	85	(33, 143, 151)
	0.95±2	18	4	8	75	(11, 46, 48, 143, 151)
	1.08	13	4	8	75	(11)
	0.86	21	4	8	75	(11)
4.00		17	4	8	75	(33)
4.37		16	4	8	75	(143)
4.80		16	4	8	75	(44, 48)
4.3±1	1.00	19	4.75	8	63	(33, 143, 151, 196)
4.38		17	5.7	8	53	(122)
	0.90	19	6	8	50	(151)
3.7	1.1	19	6	8	50	(143)
3.5	1.9	19	8	8	37.5	(143)
3.9	3.2	19	1	9	30	(143)
	1.48	19	1.36	9	22.2	(196)
3.6	0.60	17	5.3	9	5.7	(53)
3.2		18	6	9	5	(32)
2.25			6.7	9	4.5	(126)
2.97		17	7.5	9	4	(122)
3.4	0.45	15	8.1	9	3.7	(53)
2.8	0.43	17	9	9	3.3	(130)
3.4	0.39	17	1.72	10	1.75	(53)
2.4	0.30	*ca.* 19	2	10	1.5	(130)
2.1	0.20	*ca.* 19	3.3	10	0.9	(130)
2.57			3.8	10	0.8	(109)
2.29			5	10	0.6	(109)
2.24			7.5	10	0.4	(109)

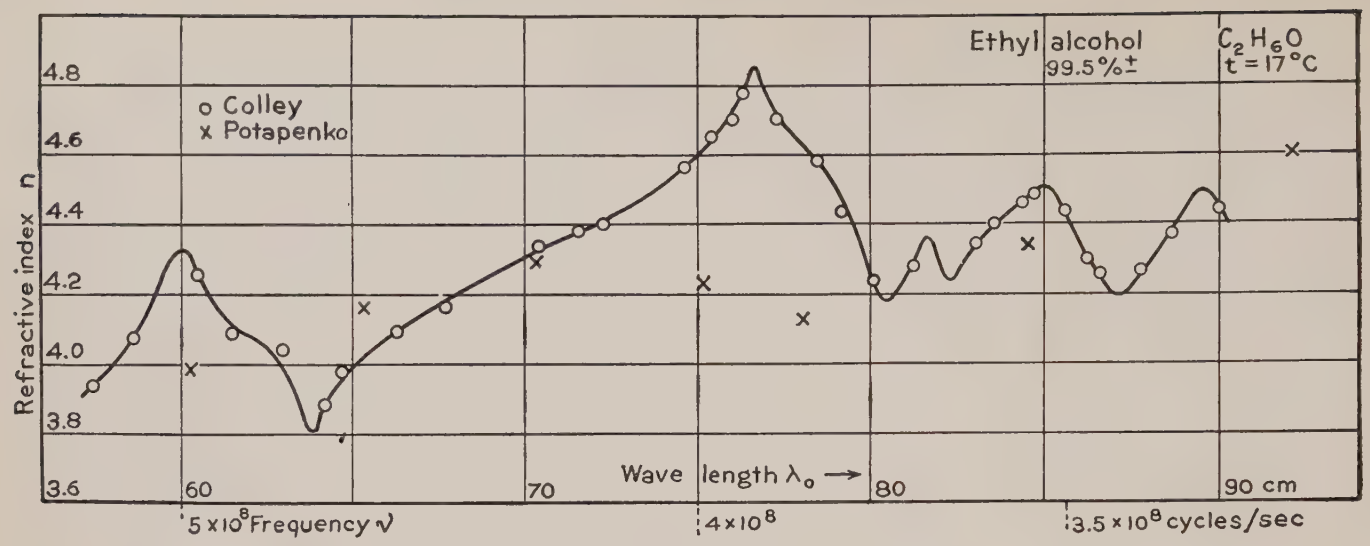

FIG. 2.—Variation of refractive index with wave-length [33, 143].

TABLE 6.—(*Continued*)

$C_2H_6O + xH_2O$, Ethyl alcohol and water

% Alc.	nk'	t	A	s	λ_0	Lit.
96	0.98	14.5	4.05	8	74	(11)
96	0.82	21	4.05	8	74	(11)
90	0.69		3.5	8	86	(151)
90	0.77		4	8	75	(151)
90	0.79		4.75	8	63	(151)
90	0.92		4.75	8	63	(196)
75	0.75		4.75	8	63	(196)
55	0.53		4.75	8	63	(196)

C_3H_6O, Acetone [34]

C_3H_8O, *n*-Propyl alcohol

n	nk'	t	A	s	λ_0	Lit.
3.84	1.57	15	4.1	8	73	(48, 49)
	1.20	20	4.05	8	74	(11)
	1.36	11	4.05	8	74	(11)
	1.5		4.76	8	63	(196)
	0.95		1.36	9	22.2	(196)
2.8	0.58	17	5.3	9	5.7	(53)
2.8	0.50	16	8.1	9	3.7	(53)
2.8	0.30	17	1.72	10	1.75	(53)

$C_3H_8O_3$, Glycerol

6.2±2	1.7		1.4	8	220	(44, 46)
	1.20	12	4.05	8	74	(11)
	1.47	20	4.05	8	74	(11)
	1.59	27	4.05	8	74	(11)
5.0	2.5	15	4.1	8	73	(46, 48)
4.5	1.9	20	4.1	8	73	(48, 49)
3.74			3.52	9	8.52	(111)
3.8	0.23	17	5.3	9	5.7	(53)
4.1			6.7	9	4.5	(125)
3.8	0.26	15	8.1	9	3.7	(53)
3.8	0.27	19	1.72	10	1.75	(53)
1.84			3.7	10	0.8	(109)
1.76			5	10	0.6	(109)
1.62			7.5	10	0.4	(109)

$\nu = 2.2 \times 10^8$, $\lambda_0 = 136$ [20]

n	nk'	t	n	nk'	t
1.67	0.02	−140	1.73	0.02	− 20
1.67	0.02	−100	1.93	0.14	0
1.70	0.02	− 40	2.36	0.52	+ 10

$C_3H_8O_3$.—(*Continued*)

n	nk'	t	n	nk'	t
3.96	1.31	20	5.67	0.11	80
5.20	1.40	30	5.50	0.11	100
5.82	0.93	40	5.38	0.11	120
5.99	0.42	50	5.08	0.10	200
5.91	0.30	60			

$C_4H_{10}O$, Isobutyl alcohol

n	nk'	t	A	s	λ_0	Lit.
	1.19	19	3	8	100	(151)
	1.14	19	4	8	75	(11, 151)
2.80	1.32	18	4.1	8	73	(48, 49)
	1.4		4.76	8	63	(196)
	1.10	19	5	8	60	(151)
	1.10	19	5.5	8	55	(151)
	1.01	19	6	8	50	(151)
	0.91	19	6.7	8	45	(151)
	0.42		1.36	9	22.2	(196)
2.4	0.31	17	5.3	9	5.7	(53)
2.4	0.26	17	8.1	9	3.7	(53)
2.4	0.25	18	1.72	10	1.75	(53)

$C_5H_{12}O$, Amyl alcohol

3.03±5		17.3	1.4	8	220	(44)
	0.97	19	3	8	100	(151)
	0.88	19	4	8	75	(151)
2.34±5	1.20	18.5	4.1	8	73	(44, 46)
	1.01	22	4.1	8	73	(48, 49)
	0.80	19	5	8	60	(151)
	0.69	19	6	8	50	(151)
1.82			6.7	9	4.5	(125)

C_6H_6, Benzene; *see* Fig. 1

C_7H_8, Toluene; *see* Fig. 1

TABLE 7.—DIELECTRIC CONSTANT (ϵ) OF CRYSTALS

$\epsilon_\parallel$, $\epsilon_\perp$ = value of ϵ when direction of the electric field is $\parallel$, $\perp$ to optic axis; crystal being uniaxial. ϵ_a, ϵ_b, ϵ_c = value of ϵ when direction of electric field is $\parallel$ to brachy (*a*), macro (*b*), *c* crystallographic axis, respectively; crystal orthorhombic. ϵ_1, ϵ_2 = value of ϵ along principal axes of the electric indicatrix $\perp$ to ortho (*b*) axis in monoclinic crystals; $\epsilon_1 > \epsilon_2$. χ = angle between the crystallographic *c*-axis and the direction corresponding to ϵ_1,

positive in direction from c-axis towards a-axis. The acute crystal angle $\beta = +c_{1-a}$ is, therefore, negative. The value of ϵ in any given direction is numerically equal to that semidiameter of the ellipsoid $\frac{x^2}{\epsilon_1^2} + \frac{y^2}{\epsilon_b^2} + \frac{z^2}{\epsilon_2^2} = 1$ which is $\parallel$ to the given direction.

ϵ_{cl} = value when field is $\perp$ plane of cleavage, ϵ_m = mean value of ϵ; for uniaxial crystals, $\epsilon_\parallel + 2\epsilon_\perp = 3\epsilon_m$; for orthorhombic crystals, $\epsilon_a + \epsilon_b + \epsilon_c = 3\epsilon_m$; for monoclinic, $\epsilon_1 + \epsilon_b + \epsilon_2 = 3\epsilon_m$; trans. = transparent; trl. = translucent. For other symbols, *see* p. 82. Unit of $\epsilon = 1$ cgse unit; of $\chi = 1°$. Frequency, $\nu = A \times 10^n$ cycle/sec.

Isometric (or regular, or cubic) system, optically isotropic

		ϵ	A	n	Lit.
NH_4Cl	Ammonium chloride	6.8	1	12	(114)
NH_4Br	Ammonium bromide	7.3	1	12	(114)
P	Phosphorus (yellow)	3.60	3	18	(167)
C	Diamond	5.5	3	18	(167)
AgCl	Silver chloride	11.20	1	5; 7	(90)
AgBr	Silver bromide	12.17	1	5; 7	(90)
$Pb(NO_3)_2$	Lead nitrate	16.8	1	12	(114)
$Al_2(NH_4)_2(SO_4)_4.24H_2O$	Ammonium alum	6.0	1	12	(114)
CaF_2	Fluorite (colorless)	6.85*	Audio		(36, 152, 175)
		6.76±4	1	5; 12	(90, 114, 155, 156)
NaCl	Rock salt	6.2±0.1	Audio		(36, 148, 181)
		5.75±5	1	5; 9	(90, 155, 156, 166, 181)
		5.9±0.1	1	12	(114, 155, 156)
$NaAlSi_2O_6.H_2O$	Analcite	6.7	1	12	(114)
KBr	Potassium bromide	5.1	1	12	(114)
KI	Potassium iodide	5.4	1	12	(114)
$K_2Al_2(SO_4)_4.24H_2O$	Potassium alum	6.5±0.2*	Audio		(36, 175)
	(19°C)	6.32	3	8	(166)
$Rb_2Cr_2(SO_4)_4.24H_2O$	Rubidium chrome alum	5.0	1	12	(114)
$Rb_2Al_2(SO_4)_4.24H_2O$	Rubidium alum	5.1	1	12	(114)
$Cs_2Al_2(SO_4)_4.24H_2O$	Cesium alum	5.0	1	12	(114)

Tetragonal, trigonal, and hexagonal systems, optically uniaxial

		$\epsilon\perp$	$\epsilon\parallel$	A	n	Lit.
SiO_2	Chalcedony	$\epsilon_m = 4.2$		1	12	(114)
TiO_2	Rutile (brown) (19°C)	86±3	170±3	1	8; 12	(115, 166)

Tetragonal, trigonal, and hexagonal systems.—(*Continued*)

		$\epsilon\perp$	$\epsilon\parallel$	A	n	Lit.
TiO_2	Rutile (trans.)	$\epsilon_m = 78\pm5$		3	8	(166)
		$\epsilon_m = 31$		3	8	(166)
$ZrSiO_4$	Zircon (trans., yellow)	12±1	12±1	1	8; 12	(115, 166)
SnO_2	Cassiterite	23.4	24.0	1	12	(114)
$Pb_5Cl(PO_4)_3$	Pyromorphite (trl., yellow)	26	150±15	3	8	(166)
(Zn, Fe, Cd)S	Wurtzite	$\epsilon_m = 8.2$		1	12	(115)
$ZnCO_3$	Smithsonite	9.3	9.4	1	12	(114)
HgCl	Calomel	14.0†		1	12	(114)
$FeCO_3$	Siderite	8.5±0.3*	8.0±0.3	2	0	(36)
	(trl.)	7.86	6.85	3	8	(166)
		7.8	6.0	1	12	(114)
$PbMoO_4$(?)	Wulfenite (red)		26.8	3	8	(167)
		$\epsilon_m = 23.8$		3	8	(167)
Al_2O_3	Corundum; sapphire	13.19	11.42	Audio		(66)
	(synthetic)	12.80	11.08	Audio		(66)
Al_2O_3	Ruby	13.27	11.28	Audio		(66)
	(synthetic)	13.38	11.08	Audio		(66)
$H_9Al_3(BOH)_2Si_4O_{19}$(?)	Tourmaline (clear)	7.10‡	6.3±2	Audio		(36, 66)
	(bright green, trans.)	6.77	5.59	3	8	(166)
		7.1	6.1	1	12	(114)
$Be_3Al_2(SiO_3)_6$	Beryl (trans., blue) (19°C)	6.08	5.53	3	8	(166)
	(trans., green) (19°C)	6.05	5.50	3	8	(166)
	(emerald)	7.6‡	6.2	1	0	(36)
	(aquamarine)	7.02	6.08	Audio		(66)
	(aquamarine)	7.4	7.8	Audio		(175)
		5.95±5	5.9±0.1	1	12	(114)
$H_8(Mg, Fe)_5Al_2Si_3O_{18}$	Penninite (trans., green) (19°C)	$\epsilon_m = 4.85$		3	8	(166)
$Ca_5(Cl, F)(PO_4)_3$	Apatite (lilac) (19°C)	9.50§	7.41	3	8	(166)
		10.5	7.7	1	12	(114)
$CaCO_3$	Calcite	8.5±0.2	8.0±0.3	Audio		(65, 141, 152, 175)
	(Iceland) (19°C)	8.5±0.2	8.0±0.2	3	8	(166)
	(deduced) (27.8°C)	$\epsilon_{cl} = 7.8$		Audio		(148)
	(deduced) (27.8°C)	$\epsilon_{cl} = 8.3\pm0.1$		1	8; 12	(155, 166, 181)
$CaCO_3$	Marble	$\epsilon_m = 8.30$		2	2; 8	(66, 90, 155, 167)
		$\epsilon_m = 8.5\pm0.3$		1	9; 12	(114, 155, 156)
$Ca_6[Al(OH, F)]Al_2(SiO_4)_5$(?)	Vesuvianite (trans.)	8.5±0.1	9.2±0.2	1	8; 12	(114, 166)
$CaMg(CO_3)_2$	Dolomite	8.0±0.2	6.8±0.1	1	8; 12	(114, 166)
$NaNO_3$	Soda nitre	6.5		1	12	(114)
$KLiSO_4$	Potassium lithium sulfate	5.4	5.7	1	12	(114)
$NaK_3(SO_4)_2$	Sodium tripotassium sulfate	7.2	5.8	1	12	(114)

For footnotes, *see* p. 100.

Monoclinic system, optically biaxial

		ϵ_1	ϵ_m	ϵ_b	ϵ_{cl}	ϵ_2	χ	A	n	Lit.
$C_{12}H_{22}O_{11}$	Cane sugar	3.49		3.32		3.16	−58.7	3	8	(52)
$Zn(NH_4)_2(SO_4)_2.6H_2O$		6.6		7.6		5.4	−82.1	1.7	2	(22)
$CuCO_3.Cu(OH)_2$	Malachite		7.2					1	12	(114)
$Mn(NH_4)_2(SO_4)_2.6H_2O$		5.9		6.8		4.6	26.0	1.7	2	(22)
$Co(NH_4)_2(SO_4)_2.6H_2O$		6.1		5.6		5.8	41.9	1.7	2	(22)
$Ni(NH_4)_2(SO_4)_2.6H_2O$		5.4		5.1		5.1	11.1	1.7	2	(22)
$Mg(NH_4)_2(SO_4)_2.6H_2O$		7.1		8.5		6.1	−28.9	1.7	2	(22)
$CaSO_4.2H_2O$	Gypsum				6.3			2	0	(36)
					5.04			Audio		(175)
					5.10			1	5; 7	(90, 181
					7.5			1	12	(155)
		9.92		5.15		5.04	102.5	3	8	(166)
		11.6				5.4	− 1.0	1	12	(157)
$CaMg.Si_2O_6.x(Mg, Fe)(Al, Fe)SiO_6$(?)	Augite	8.57		6.90		7.07	−55.6	3	8	(52)
		10.3				7.3	−55	1	12	(157)
$Na_2HAsO_4.12H_2O$			6.2	5.9				1.7	2	(22)
$K_2Co(SO_4)_2.6H_2O$		9.4		10.7		8.5	−75.1	1.7	2	(22)
$K_2Ni(SO_4)_2.6H_2O$		6.4		7.1		5.5	15.0	1.7	2	(22)
$KAlSi_3O_8$	Adular	5.33		5.50		4.54	42.5	3	8	(52)
		6.2				4.8	2.5	1	12	(157)

Orthorhombic system, optically biaxial

		ϵ_a	ϵ_m	ϵ_b	ϵ_{cl}	ϵ_c	A	n	Lit.
S	Sulfur		4.0				2	0	(36)
		3.81		3.97		4.77	3.2	1	(21)
		3.67		3.87		4.66	1.7	2	(22)
	(trans., from CS_2) (19°C)	3.59		3.83		4.61	3	8	(166)
$C_6H_8O_7$	Citric acid	4.7		4.3		3.3	1.7	2	(22)
$PbCl_2$	Lead chloride		42±2.0				3	8	(167)
			40±3.0				1	12	(114, 155)
$PbCO_3$	Cerussite	25.4‖		23.0		19.6	3	8	(166)
		24.2±0.3		25.0±0.3		26.3±0.3	1	12	(114)
$HgCl_2$	Mercuric chloride		6.55±5				1	12	(114, 155)
$(AlF)_2SiO_4$	Topaz				6.53*		2	0	(36)
		6.25‖		6.53		6.44	Audio		(66)
	(trans., yellow) (19°C)	6.68		6.71		6.28	3	8	(166)
		7.4		7.3		7.6	1	12	(114)
$MgSO_4.7H_2O$	Magnesium sulfate	5.3		6.1		8.3	1.7	2	(22)
$CaSO_4$	Anhydrite (trans.) (19°C)			5.70±5		6.30±5	1	8; 12	(114, 166)
$CaCO_3$	Aragonite	9.1				6.0	Audio		(65)
	(19°C)	9.87±3‖		7.72±3		6.59±3	3	8	(166)
		6.7		10.5		7.6	1	12	(114)
$SrSO_4$	Celestite (trans.)	7.9§		18.5		8.30	3	8	(166)
		9.3		44†		8.5	1	12	(114)
$SrCO_3$	Strontianite	6.6				6.5	1	12	(115)
$BaSO_4$	Barite	7.0		11.0		7.0	Audio		(65)
		7.68		12.2		7.70	3	8	(166)
		9.1				9.8	1	12	(114)
$BaCO_3$	Witherite (19°C)	7.8±0.1‖		7.5±0.1		6.4±0.1	3	8	(166)
				7.5		7.3	1	12	(114)
$KNaC_4H_4O_6.4H_2O$	Rochelle salt¶ (0°C)	800					0	0	(186)
	(0°C)	700					3.3	1	(186)
		6.7		6.9		8.9	1.7	2	(22)
	0°C	112					40; 8	3	(70)
	0°C	70					4	5; 7	(70)
	15°C	80					4	5; 7	(70)
K_2SO_4	Potassium sulfate	6.1		5.7		4.5	1.7	2	(22)

Triclinic system (no data available)

* Very small absorption.
† Probably too great.
‡ Large absorption.
§ Local impurities, inclusions.
‖ Colorless.
¶ Behavior anomalous −20 to +25°C. At low frequencies, measurements are affected by mechanical vibration, fatigue, and absorption.

Table 8.—Dielectric Constant (ϵ) of Binary Mixtures and Solutions

For data below −80°C, *see* Table 10; for solutions of oleates, *see* Table 9; for mixtures of gases, *see* Table 3; for colloidal suspensions, *see* Table 11.

Concentrations are expressed in terms of the amount of the B-component contained in the mixture, except in a few cases in which the A-component is a solid, or the volume % of A is given. An asterisk (*) indicates that all values of that series have been recalculated so as to make them correspond to the values adopted (Table 1) for the standardizing liquids.

The frequency (cycles per sec) of the applied emf and the temperature are given immediately below the B-component.

The concentration of component (A), (B) is indicated in each case by one of the symbols M_B, M %, N', Vol. %, Wt. %. M_B = molar concentration, unit = 1 gram mole B per liter of solution; M % B = molecular percentage, unit = 1 gram mole B per 100 gram moles of the mixture, the total number of moles of the mixture being assumed equal to the sum of those of its pure constituents; N' = thousandth normal, unit = 1 gram equivalent of B per 1000 liters of the mixture; Vol. % = volume percentage, unit = 1 cm^3 of pure A, or B, per 100 cm^3 of mixture; Wt. % B = weight percentage, unit = 1 gram B per 100 grams of mixture. t = centigrade temperature, °C; for other symbols, *see* p. 82.

1. Aqueous Solutions

Unit of ϵ = 1 cgse unit

B = CH_4N_2O, Urea (80)

M_B = 5.6 × 10^5; ϵ at 20°C (80)

M_B	ϵ
0.5	80.22
1.0	81.51
1.5	82.81
2.0	83.98
2.5	85.16
3.0	86.17

B = CH_4O, Methyl alcohol (49)

ϵ = 4 × 10^8; 17°C

Wt. % B	ϵ
0.0	82.6*
10.0	77.6

B = CH_4O.— (*Continued*)

5.6 × 10^5; 18°C (59)

Wt. % B	ϵ
20.0	72.8
40.0	63.0
60.0	52.2
80.0	42.6
100.0	33.8
20.0	69.6
40.0	61.4
60.0	52.4
80.0	43.1
100.0	33.8

B = $C_2H_3Cl_3O_2$, Chloral hydrate (174)

ϵ = 4 × 10^8; 21.8°C

M % B	ϵ
40.8	33.5±1.0

B = C_2H_5NO, Acetamide (174)

ϵ = 4 × 10^8, 21.7°C

M %B	ϵ
40.7	7.2±0.2

B = $C_2H_5NO_2$, Glycocoll (72)

Wt. % B	ϵ
4×10^8; 20°C	
0.0	81.9*
1.0	86.9
4.0	90.8
8.0	93.4
16.0	94.7

B = C_2H_6O, Ethyl alcohol (133) *See also* Table 6

Wt. % B	ϵ
Audio; 20°C	
50.0	49.4*
60.0	43.9
70.0	38.7
80.0	34.1
90.0	29.8
100.0	26.5

B = C_3H_6O, Acetone (49)

4.0×10^8; 19°C	
0.0	81.8*
25.0	67.7
50.0	51.2
80.0	32.2
100.0	20.7

B = $C_3H_6O_2$, Propionic acid (49)

4×10^8; 17°C	
55.0	43.8*
60.0	29.7
62.5	25.4
65.0	24.9
70.0	24.7
75.0	23.4
80.0	19.4
90.0	10.9
95.0	6.8

B = $C_3H_7NO_2$, Urethane (174)

M % B	ϵ
4×10^8; 21.7°C	
35.5	32 ± 1

B = $C_4H_5NO_2$, Succinimide (174)

M % B	ϵ
4×10^8; 22.3°C	
5.2	5.8 ± 1.0

B = $C_6H_6O_2$, Resorcinol (174)

M %B	ϵ
4×10^8; 21.8°C	
17.8	3.2 ± 0.2

B = $C_6H_{12}O_6$, Dextrose (72)

Wt. % B	ϵ
4×10^8; 20°C	
0.0	81.9*
10.0	68.4
20.0	55.7
30.0	42.8
40.0	30.3

B = $C_6H_{12}O_6$, Levulose (72)

4×10^8; 20°C	
0.0	81.9*
10.0	73.3
20.0	59.3
30.0	45.4
40.0	31.4

B = $C_6H_{14}O_6$, Mannitol (174)

M % B	ϵ
4×10^8; 22.0°C	
1.8	3.0 ± 0.2

B = $C_7H_5NO_3S$, Saccharin (72)

Wt. % B	ϵ
4×10^8; 20°C	
0.0	81.9*
0.10	85.5
0.25	91.1
0.50	87.7
1.00	78.6
2.00	73.6
10.0	58.5
20.0	48.3
30.0	39.2

B = $C_{12}H_{22}O_{11}$, Cane sugar (72)

4×10^8; 20°C	
0.0	81.9*
10.0	80.9
20.0	75.3
30.0	68.2
50.0	49.9
60.0	39.7
5.6×10^5; 18°C (80)	
5.0	77.14
10.0	76.16
20.0	74.05
25.0	72.94
30.0	71.52

B = $C_{18}H_{27}NO_3S$, Tetraethyl ammonium naphthalene-β-sulfonate (112)

N'	ϵ
7×10^6; 20°C	
2	75.1
5	66.9

B = Albumin (72)

Wt. % B	ϵ
4×10^8; 20°C	
0.0	81.9*
0.50	71.8
1.00	67.0
4.00	52.3
6.00	47.8
15.00	33.4

B = Gelatin (72)

4×10^8; 20°C	
0.0	81.9*
5.00	68.2
10.0	60.2
20.0	53.4
30.0	49.6
50.0	44.8

B = Pepsin (72)

4×10^8; 20°C	
1.0	79.9*
2.0	77.4

B = Trypsin (72)

4×10^8; 20°C	
0.25	83.9*
0.50	85.5

B = $CuSO_4$, Copper sulfate (112)

N'	ϵ
7×10^6; 20°C	
1.14	73.5
2.28	75.8
4.58	72.1

B = KCl, Potassium chloride (112)

9×10^6; 20°C	
0.755	78.6
7×10^6; 20°C	
0.755	73.4
1.51	74.4
7.55	65.1

For various other electrolytes consult the current literature.

2. Non-Aqueous Solutions; The C-Arrangement; *v.* Vol. III, p. viii

CCl_4 Carbon tetrachloride

B = CS_2, Carbon disulfide (42, 77, 116)

Wt. % B	ϵ
Audio; 20°C	
20	2.31
40	2.39
60	2.47
80	2.56
100	2.66
Wt. % B	∂
(10 t 45)	
20	− 0.14
40	− 0.15
(10 t 55)	
60	− 0.18
(10 t 40)	
80	− 0.18

B = $C_2H_4Br_2$, Ethylene bromide (42)

Wt. % B	ϵ
Audio; 23°C	
30	2.59
50	3.02
70	3.38
90	3.85

B = C_2H_6O, Ethyl alcohol (105)

10^3; 20°C	
0	2.25
10	5.40
20	8.60
30	11.7
40	14.5
50	17.0
60	19.1
70	20.9
80	22.6
90	24.2
100	25.8

B = $C_4H_{10}O$, Ethyl ether (42)

Audio; 19.0°C	
0.0	2.26
20.0	2.98
40.0	3.53
80.0	4.25
100.0	4.55

B = C_6H_5Cl, Chlorobenzene (16)

Vol. % A	ϵ
Audio; 15°C	
20	2.91
30	3.35
50	3.95
80	5.02

B = C_6H_6, Benzene (116)

M % B	ϵ
Audio; 20°C	
0.0	2.27*
25.0	2.22
60.0	2.22
75.0	2.23
100.0	2.28

B = $C_7H_{16}O$, Ethyl amyl ether (42)

Wt. % B	ϵ
Audio; 22.9°C	
20.0	2.64
50.0	3.17
70.0	3.28
90.0	3.40

B = C_8H_{10}, *m*-Xylene (42)

Audio; 20°C	
10	2.27
40	2.31
70	2.34
90	2.37

B = Oleates, *see* Table 9

CS_2 Carbon disulfide

B = S, Sulfur (54)

Wt. % B	ϵ
4×10^8; 19°C	
0.0	2.67*
5.0	2.44
10.0	2.22
20.0	2.10
25.0	2.10

B = $CHCl_3$, Chloroform (139)

Audio; 18°C	
20.0	2.95*
30.0	3.17
40.0	3.38
60.0	3.78
80.0	4.23
Audio; 19°C (42)	
20.0	2.70
40.0	3.28
80.0	4.47

B = $C_2H_4Br_2$, Ethylene bromide (42)

Audio; 22.4°C	
40.0	3.02
60.0	3.37
70.0	3.68
90.0	4.36

B = C_2H_6O, Ethyl alcohol (139)

Wt. % B	ϵ
Audio; 18°C	
30.0	22.7*
40.0	19.80
60.0	14.00
80.0	8.25
100.0	2.64

B = $C_4H_{10}O$, Ethyl ether (116)

Audio; 20°C	
0.0	2.65*
40.0	3.33
80.0	4.00
100.0	4.39

B = C_6H_5Br, Bromobenzene (42)

Audio; 20°C	
20.0	3.03
40.0	3.72
60.0	4.42
80.0	5.12
100.0	5.82

B = C_6H_6, Benzene (77)

10^6; 20°C	
40.0	2.384
60.0	2.321
80.0	2.305
Wt. % B	∂_t
(10 t 40)	
40.0	− 0.16
60.0	− 0.17
80.0	− 0.19

B = C_7H_8, Toluene (42)

Wt. % B	ϵ
Audio; 20.0°C	
20.0	2.60
50.0	2.52
70.0	2.44
90.0	2.35

B = C_7H_{16}, Heptane (42)

Audio; 22.5°C	
0.0	2.74
10.0	2.50
30.0	2.21
40.0	2.205
50.0	2.202
60.0	2.15

B = C_8H_{10}, *m*-Xylene (16)

Vol. % B	ϵ
Audio; 15°C	
0.0	2.61
40.0	2.52
60.0	2.47
80.0	2.43
100.0	2.37

CS_2.—(*Cont'd*)

B = Oleates; *see* Table 9

$CHCl_3$

Chloroform

B = $C_2H_4Br_2$, Ethylene bromide (42)

Wt. % B	ϵ
Audio; 22.4°C	
20.0	4.89
40.0	4.88
60.0	4.87
70.0	4.86
90.0	4.84

B = C_2H_6O, Ethyl alcohol (42, 77)

Audio; 20°C	
20.0	4.33
40.0	3.74
60.0	3.15
80.0	2.64
Wt. % B	∂_{20}
20.0	− 1.35
40.0	− 0.95
60.0	− 0.65
80.0	− 0.37

B = $C_4H_{10}O$, Ethyl ether (35, 139, 168)

Wt. % B	ϵ
Audio; 20°C	
0.0	4.36
20.0	5.85
40.0	5.83
60.0	5.36
80.0	4.81
100.0	4.44

B = C_6H_{10}, Amylene (42)

Audio; 21.2°C	
10.0	4.44
20.0	3.92
40.0	3.08
60.0	2.61
80.0	2.28

B = C_5H_{12}, Pentane (42)

Audio; 21.7°C	
10.0	4.39
20.0	3.77
40.0	2.89
60.0	2.39
80.0	2.10

B = C_6H_6, Benzene (42)

Audio; 19°C	
20.0	3.97
30.0	3.66
50.0	3.22
70.0	2.83
90.0	2.29

B = C_7H_{16}, Heptane (42)

Wt. % B	ϵ
Audio; 20.2°C	
0.0	5.10
20.0	3.87
40.0	3.03
60.0	2.47
80.0	2.18

B = $C_7H_{16}O$, Ethyl amyl ether (42)

Audio; 23.3°C	
0.0	4.97
10.0	5.29
30.0	5.34
50.0	5.03
80.0	3.90
100.0	3.56

B = Oleates; *see* Table 9

CH_4N_2O

Urea

B = CH_4O, Methyl alcohol (174)

M % A	ϵ
4×10^8; 22.1°C	
10.4	44 ± 1

B = C_2H_6O, Ethyl alcohol (174)

4×10^8; 22.0°C	
4.0	25.0 ± 0.5

CH_4O

Methyl alcohol

B = $C_3H_7NO_2$, Urethane (174)

M % B	ϵ
4×10^8; 21.6°C	
55.5	18.0 ± 0.5

B = C_6H_6, Benzene (139)

Wt. % B	ϵ
Audio; 16°C	
95.0	2.96*
96.0	2.80
97.0	2.66
99.0	2.37

B = C_7H_8, Toluene (139)

Audio; 16°C	
96.0	2.87*
97.0	2.75
98.0	2.62
99.0	2.49

B = C_8H_9NO, Acetanilide (174)

M % B	ϵ
4×10^8; 22.2°C	
10.5	37.0 ± 1.0

B = $C_{10}H_8$, Naphthalene (174)

4×10^8; 22.1°C	
1.8	30.0 ± 1.0

$C_2H_3Cl_3O_2$

Chloral hydrate

B = C_2H_6O, Ethyl alcohol (174)

M % A	ϵ
4×10^8; 21.5°C	
51.3	13.0 ± 0.2

B = C_7H_8, Toluene (174)

4×10^8; 21.9°C	
13.1	3.0 ± 0.2

$C_2H_4Br_2$

Ethylene bromide

B = $C_4H_{10}O$, Ethyl ether (42)

Wt. % B	ϵ
Audio; 22.0°C	
20	4.94
40	4.79
60	4.64
80	4.50

B = C_6H_{10}, Amylene (42)

Audio; 21.4°C	
20	3.35
40	2.60
60	2.33
80	2.17
100	2.07

B = C_6H_6, Benzene (42)

Audio; 23.1°C	
20.0	3.78
60.0	2.72
80.0	2.48
100.0	2.284

B = C_7H_{16}, Heptane (42)

Audio; 22.7°C	
0	4.92
20	3.22
40	2.57
60	2.29
80	2.15

C_2H_5NO

Acetamide

B = C_2H_6O, Ethyl alcohol (174)

M % A	ϵ
4×10^8; 22.0°C	
35.6	45.0 ± 1.0

C_2H_6O

Ethyl alcohol

B = $C_3H_7NO_2$, Urethane (174)

M % B	ϵ
4×10^8; 21.6°C	
52.0	16 ± 0.5

B = $C_4H_5NO_2$, Succinimide (174)

4×10^8; 21.8°C	
2.3	23.0 ± 0.5

B = $C_4H_{10}O$, Ethyl ether (105)

Wt. % B	ϵ
10^3; 20°C	
0	25.8
10	23.2
20	20.6
30	18.0
40	15.5
50	13.10
60	10.90
70	8.90
80	7.20
90	5.70
100	4.35

B = C_6H_6, Benzene (105)

Audio; 20°C	
0.0	25.80
10.0	23.20
20.0	20.60
30.0	18.00
40.0	15.50
50.0	13.10
60.0	10.80
70.0	8.60
80.0	6.50
90.0	4.30
100.0	2.28

B = $C_6H_6O_2$, Resorcinol (174)

M % B	ϵ
4×10^8; 22.0°C	
40.3	11.5 ± 0.5

B = C_7H_8, Toluene (139)

Wt. % B	ϵ
Audio; 16°C	
96.0	2.67*
97.0	2.59
98.0	2.51

B = C_7H_9N, *p*-Toluidine (174)

M % B	ϵ
4×10^8; 21.7°C	
50.0	10.0 ± 0.5

B = C_8H_9NO, Acetanilide (174)

4×10^8; 21.8°C	
9.4	29.0 ± 0.5

B = $C_{10}H_8$, Naphthalene (174)

4×10^8; 21.5°C	
3.3	22.0 ± 0.5

C_3H_6O

Acetone

B = C_6H_6, Benzene (49)

Wt. % B	ϵ
4×10^8; 20°C	
0.0	20.5*
20.0	16.8

B = C_6H_6.—(*Continued*)

Wt. % B	ϵ
60.0	8.49
80.0	3.59
100.0	2.28
Wt. % B	∂_{20}
0.0	−12.36
20.0	− 8.80
40.0	− 3.41
80.0	− 1.08
100.0	− 0.23

B = C_7H_8, Toluene (5)

Wt. % B	ϵ
5×10^8; 17°C	
20.0	16.9
40.0	13.1
60.0	9.48
80.0	3.97

$C_3H_7NO_2$

Urethane

B = C_3H_8O, Propyl alcohol (174)

M % A	ϵ
4×10^8; 20.9°C	
52.5	15.5 ± 0.5

B = C_7H_8, Toluene (174)

4×10^8; 21.7°C	
19.2	3.0 ± 0.2

C_3H_8O

Propyl alcohol

B = C_6H_6, Benzene (139)

Wt. % B	ϵ
Audio; 16°C	
30.0	13.76*
50.0	9.82
70.0	5.975
80.0	4.05

B = $C_{10}H_8$, Naphthalene (174)

M % B	ϵ
4×10^8; 22.0°C	
3.8	18.0 ± 0.5

$C_4H_8O_2$

Ethyl acetate

B = C_6H_6, Benzene (116)

M % B	ϵ
Audio; 20°C	
0.0	6.235*
20.0	5.54
50.0	3.22
80.0	2.90
100.0	2.278

$C_4H_{10}O$

Ethyl ether

B = C_5H_{12}, Pentane (42)

Wt. % B	ϵ
Audio; 20.7°C	
20	3.87
40	3.08
60	2.56
80	2.17
100	1.84

B = C_6H_6, Benzene (139)

Audio; 18°C	
0.0	4.278*
20	3.86
40	3.45
60	3.05
80	2.67
Audio; 17.8°C (42)	
20	4.12
40	3.66
60	3.20
80	2.73

B = $C_{10}H_7Br$, α-Bromonaphthalene (42)

Audio; 19.6°C	
30.0	4.60
50.0	4.87
70.0	5.03
80.0	5.04
90.0	4.98
100.0	4.912

$C_4H_{10}O$

Isobutyl alcohol

B = C_8H_{10}, *m*-Xylene (91)

Wt. % B	ϵ
13.25°C	
40.0	10.8*
50.0	8.82
80.0	3.40

C_5H_5N

Pyridine; *see* Table 9

$C_5H_{11}Cl$

Amyl chloride

B = C_8H_{10}, *m*-Xylene (91)

Wt. % B	ϵ
16.4°C	
40.0	4.55*
60.0	3.8
80.0	3.1

$C_5H_{12}O$
Amyl alcohol

B = C_6H_6, Benzene (139)

Wt. % B	ϵ
Audio; 16°C	
76.0	3.31*
80.0	3.04
88.0	2.65
92.0	2.54
96.0	2.41

B = C_8H_{10}, *m*-Xylene (91)

14°C	
30.0	10.7*
40.0	6.75
70.0	4.05
80.0	3.20

C_6H_5Br
Bromobenzene

B = C_6H_6, Benzene (42)

Wt. % B	ϵ
Audio; 22.35°C	
20.0	4.53
40.0	3.75
60.0	3.12
80.0	2.62

C_6H_5Cl
Chlorobenzene

B = C_7H_{16}, Heptane (42)

Wt. % B	ϵ
Audio; 22.4°C	
20.0	4.65
40.0	3.73
60.0	3.20
80.0	2.41
100.0	1.97

B = $C_7H_{16}O$, Ethyl amyl ether (42)

Audio; 22.35°C	
20.0	5.33
40.0	4.88
60.0	4.42
80.0	3.98
100.0	3.55

B = C_8H_{10}, *m*-Xylene (42)

Wt. % A	ϵ
Audio; 20.2°C	
10.0	2.60
30.0	3.20
50.0	3.78
80.0	4.68

B = C_8H_{10}.— (*Continued*)

Vol. % A	ϵ
Audio; 15°C (16)	
0.0	2.37
20.0	3.10
60.0	4.53
100.0	5.98

$C_6H_5NO_2$
Nitrobenzene

B = C_6H_6, Benzene (139)

Wt. % B	ϵ
Audio; 16°C	
0.0	37.93*
20.0	24.10
40.0	16.70
60.0	9.55
80.0	5.50
100.0	2.291

B = $C_6H_{11}N$, Capronitrile (99)

4×10^8; 23°C	
50.0	19.6
60.0	18.1
70.0	17.1

B = C_7H_8, Toluene (139)

Audio; 16°C	
0.0	37.92*
20.0	25.7
40.0	17.2
80.0	5.7
100.0	2.39

B = **Oleates**; *see* Table 9

C_6H_6
Benzene

B = C_6H_6O, Phenol (140)

Wt. % B	ϵ
Audio; 20°C	
5.0	2.33
15.0	2.88
25.0	3.63

B = C_7H_8, Toluene (77)

10^6; 20°C	
20.0	2.277
40.0	2.287
60.0	2.296
80.0	2.324
Wt. % B	∂_t
(10 *t* 75)	
20.0	− 0.14
40.0	− 0.14
60.0	− 0.125
80.0	− 0.12

B = C_7H_8O, *o*-Cresol (140)

Wt. % B	ϵ
Audio; 20°C	
5.0	2.83
10.0	2.57
15.0	2.73
25.0	3.04

B = C_7H_8O, *m*-Cresol (140)

Audio; 20°C	
5.0	2.44
15.0	2.87
20.0	3.12

B = C_7H_8O, *p*-Cresol (140)

Audio; 20°C	
5.0	2.44
10.0	2.67
20.0	3.16
25.0	3.40

B = C_7H_8O, Phenyl methyl ether (140)

Audio; 20°C	
5.0	2.39
15.0	2.57
25.0	2.64

B = $C_8H_{10}O$, *o*-Tolyl methyl ether (140)

Audio; 20°C	
5.0	2.355
15.0	2.48
25.0	2.59

B = $C_8H_{10}O$, *m*-Tolyl methyl ether (140)

Audio; 20°C	
5.0	2.37
15.0	2.53
25.0	2.68

B = $C_8H_{10}O$, *p*-Tolyl methyl ether (140)

Audio; 20°C	
5.0	2.365
15.0	2.51
25.0	2.665

B = $C_{10}H_{16}O$, Camphor (54)

4×10^8; 24.0°C	
0.00	2.27
5.00	2.53
10.0	2.94
15.0	3.54
20.0	4.60
25.0	6.02

B = $C_{10}H_{20}O$, Menthol (54)

Wt. % B	ϵ
4×10^8; 23°C	
0.00	2.26
5.00	2.59
15.0	3.54
25.0	4.58

B = **Oleates**; *see* Table 9

B = **Castor Oil** (185)

Audio; 20°C	
10.0	2.55*
20.0	2.76
30.0	2.85
40.0	3.09
50.0	3.44
60.0	3.62
70.0	4.06
80.0	4.22
90.0	4.59
Wt. % B	∂_{20}
30.0	− 0.09
40	− 0.20
50	− 0.33
60	− 0.45
70	− 0.58
80	− 0.70
90	− 0.93

C_6H_6O
Phenol

B = C_8H_{10}, *m*-Xylene (140)

Wt. % A	ϵ
Audio; 20°C	
5.0	2.57
15.0	2.87
25.0	3.16

C_6H_7N
Aniline

B = C_8H_{10}, *m*-Xylene (100)

Wt. % B	ϵ
4×10^8; 18°C	
0.0	6.50*
20.0	5.63
60.0	3.93
80.0	3.19
100.0	2.44

$C_6H_{11}N$
Capronitrile; *see* Table 9

C_7H_8
Toluene

B = C_7H_{16}, Heptane (42)

Wt. % B	ϵ
Audio; 21.1°C	
20.0	2.285
40.0	2.215

B = C_7H_{16}.— (*Continued*)

Wt. % B	ϵ
60.0	2.146
80.0	2.075

B = $C_9H_{10}O_2$, Ethyl benzoate (116)

M % B	ϵ
Audio; 20°C	
0.0	2.387
40.0	3.35
60.0	3.84
80.0	4.33
100.0	4.915

B = $C_{10}H_8$, Naphthalene (174)

4×10^8; 22.6°C	
22.5	2.8±0.2

B = $C_{10}H_{16}$, Turpentine (116)

Audio; 20°C	
0.0	2.39*
20.0	2.23
60.0	2.22
80.0	2.20
100.0	2.19

B = $C_{12}H_{10}$, Acenaphthene (174)

4×10^8; 22.0°C	
15.4	2.8±0.2

B = $C_{14}H_{10}$, Phenanthrene (174)

4×10^8; 21.7°C	
21.0	2.3±0.2

B = **Petroleum** (170)

Wt. % B	ϵ
Audio; 11°C	
0.0	2.70*
20.0	2.55
40.0	2.47
60.0	2.37
80.0	2.21
100.0	2.08
Audio; 21°C	
0.0	2.55*
20.0	2.44
40.0	2.34
60.0	2.27
80.0	2.15
100.0	2.04

B = **Castor oil** (170)

Audio; 20°C	
0.0	2.56
20.0	2.94
40.0	3.38
60.0	3.71
80.0	4.21
100.0	4.61

C_7H_8O
Phenyl methyl ether

B = C_8H_{10}, *m*-Xylene (140)

Wt. % B	ϵ
Audio; 20°C	
75.0	2.79
85.0	2.63
95.0	2.47

C_7H_{16}
Heptane

B = $C_{10}H_7Br$, α-Bromonaphthalene (42)

Wt. % B	ϵ
Audio; 20.8°C	
40	2.63
50	2.84
70	3.42
80	3.87

Petroleum

B = $C_{10}H_{16}$, Turpentine (6)

Wt. % B	ϵ
Audio; 20°C	
0	2.03
20	2.08
40	2.11
60	2.16
80	2.20
100	2.27
Wt. % B	∂_{20}
0	− 0.20
20	− 0.31
40	− 0.60
60	− 0.80
80	− 0.91
100	− 0.96

B = **Castor oil** (6)

Wt. % B	ϵ
Audio; 20°C	
0	2.03
20	2.60
40	2.93
60	3.40
80	3.93
100	4.46
Wt. % B	∂_{20}
0	− 0.20
20	− 0.20
40	− 0.80
60	− 2.86
80	− 3.01
100	− 3.77

Cottonseed oil
See Table 9

Kerosene
See Table 9

TABLE 9.—DIELECTRIC CONSTANT (ϵ) OF SOLUTIONS OF THE OLEATES OF THE HEAVY METALS

Solvents: (1) CCl_4, Carbon tetrachloride; (2) CS_2, Carbon disulfide; (3) $CHCl_3$, Chloroform; (4) C_5H_5N, Pyridine; (5) $C_6H_5NO_2$, Nitrobenzene; (6) C_6H_6, Benzene; (7) $C_5H_{11}CN$, Capronitrile; (8) Cottonseed oil; (9) Kerosene. All values of ϵ have been recalculated to accord with the values given in Table 1. $\nu = 4 \times 10^8$; C = concentration of the oleate of the metal named in first column. Unit of $C = 1\%$ by weight; of $\epsilon = 1$ cgse; t = centigrade temperature, °C.

	(1) CCl_4 (99)			(2) CS_2 (99)			(3) $CHCl_3$ (42)		
	C	t	ϵ	C	t	ϵ	C	t	ϵ
Al	50	17.0	2.17	50.0	19.0	2.42	50.0	24.0	3.38
Cd				2.0	22.0	2.92	2.0	19.0	4.34
Co	8	17.0	2.17	4.0	24.0	2.67	10.0	20.0	4.24
Cr	4	19.0	2.29						
Cu	15	19.0	2.17	15.0	24.0	2.54	15.0	19.0	4.39
Fe	4	20.0	2.17	5.0	24.0	2.72	8.0	20.0	4.34
Mg	8	19.0	2.07						
Mn	6	19.0	2.02	2.0	19.0	2.72	15.0	20.0	4.34
Ni	15	19.0	2.26	15.0	24.0	2.57	15.0	19.0	4.66
Zn	15	19.0	2.23				15.0	20.0	4.39

	(4) C_5H_5N (99)			(5) $C_6H_5NO_2$ (99)			(6) C_6H_6 (99)		
Al	50	25.5	7.36	50	22.0	13.1	50	17.0	2.62
Cd	8	25.0	11.0				5	19.5	2.23
Co	10	24.0	11.9				25	20.0	2.37
Cu	20	24.0	10.8	10	21.0	24.5	20	19.5	2.07
Fe	10	24.0	12.0				10	20.0	2.07
Mg	15	25.0	11.7				20	20.0	2.27
Mn	15	25.5	9.88				10	20.0	2.17
Ni	25	24.0	10.1	10	22.0	25.9	20	19.5	2.37
Zn	25	24.0	10.3				25	20.0	2.02

	(7) $C_5H_{11}CN$ (99)			(8) Cottonseed oil (99)			(9) Kerosene (99)		
Al	30	18.0	10.9	50	20.0	2.30	50	20.0	1.26
Cu	10	18.0	13.4	10	20.0	2.40	5	20.0	1.51
Fe	5	18.0	13.3						
Mg	5	18.0	13.5	5	20.0	2.65	5	20.0	1.21
Mn				10	20.0	2.67	5	19.5	1.41
Ni	10	18.0	13.3				5	20.0	1.26
Zn	10	18.0	12.8	15	20.0	2.57	8	20.0	1.21

TABLE 10.—DIELECTRIC CONSTANT (ϵ) OF SOLUTIONS AT TEMPERATURES BELOW − 100°C

Aqueous Solutions

Concentration (=weight % of solute) is stated in center of column. Centigrade temperatures

B = H_2SO_4 (67)

$-t$	ϵ
10% B	
140	8.1
150	5.3
170	4.1
180	4.1

B = NH_4OH (67)

34.94% B	
140	36.0
150	10.7
160	5.1
170	4.5

B = PbO + xKOH (39)

B = $Pb(NO_3)_2$ (39)

B = $CuSO_4$ (67)

$-t$	ϵ
10% B	
110	46.7
120	21.8
130	12.5
140	7.8
160	3.8
170	3.2
180	2.8

B = $(NH_4)_2MoO_4$ (39)

$-t$	ϵ
10% B	
80	96.5
110	91.6
140	84.0

B = $Cd_2B_2W_9O_{32}$ (39)

B = $Ba(OH)_2$ (39)

Suspension

$-t$	ϵ
5% B	
130	39.5
140	35.0
160	26.4
180	19.5
184	17.2
185	16.0

B = $BaCl_2$ (39)

23% B	
100	49.8
110	27.8
120	16.8
140	7.90
160	2.80
190	2.62

B = LiOH (39)

5% B	
120	7.6
160	3.47
170	3.25
190	3.10

B = NaOH (39)

5% B	
160	142
170	145
180	140
190	130
10% B (67)	
140	131
160	83.9
180	54.6

B = NaCl (67)

10% B	
100	47.5
110	23.5
120	15.8
130	9.2
150	3.2
180	3.0

B = $NaClO_4$ (39)

10% B	
90	98.5
110	44.7
130	14.2
150	8.7
170	7.2
180	6.9

B = Na_2SO_4 (39)

10% B	
90	10.0
120	8.6
150	7.0
180	5.8

B = $NaHSO_4$ (39)

10% B	
150	15.2
170	8.9
180	5.7

B = $NaNO_2$, (39)

$-t$	ϵ
10% B	
100	51.6
115	36.8
125	13.9
160	3.00
180	2.78

B = Na_2HPO_4 (39)

10% B	
100	87.5
120	57.2
140	37.2
160	33.2
180	31.9

B = Na_2CO_3 (39)

6% B	
90	125
120	69.0
130	50.5
140	44.5
160	41.9
180	37.5

B = $NaHCO_3$ (39)

6% B	
90	74.3
110	70.2
140	59.4
160	35.5
170	4.60
180	2.90

B = CH_3CO_2Na (39)

5% B	
110	61.8
120	58.8
130	54.1
140	44.2
160	12.5
170	6.2
180	4.5

B = Na_2SiO_3 (39)

5% B	
100	138
120	131
140	127
160	123
180	104

B = $Na_2B_4O_7 \cdot 10H_2O$ (39)

15% B	
100	123
120	105
140	92.2
160	87.8
170	83.9
180	71.0

B = KOH (67)

0.05% B	
120	42.7
130	26.5
140	20.5
170	16.6
190	9.5

B = KOH.—(*Continued*)

$-t$	ϵ
10% B	
150	91.8
170	88.5
180	83.8
190	56.5
20% B	
160	48.2
170	46.2
190	39.8
50% B	
130	26.6
140	23.0
190	15.2

B = KI (39)

52.17% B	
140	21.0
160	6.9
170	3.9
180	3.0

B = KSH (39)

B = $KHCO_3$ (39)

10% B	
120	33.3
140	14.0
150	5.30
160	2.20
180	2.10

B = KCN (67)

5% B	
150	39.5
160	20.0
170	8.00
180	3.0

B = $K_4Fe(CN)_6$ (39)

12% B	
95	138
100	111
120	71.3
140	47.1
160	41.9
180	38.6

B = K_2CrO_4 (39)

36% B	
100	19.5
120	14.5
140	13.2
160	12.3
180	11.1

B = $K_2Al_2(SO_4)_4 \cdot 24H_2O$ (39)

9% B	
120	32.5
130	24.4
150	14.4
170	6.8
180	3.4

B = RbOH (39)		B = RbOH.—(Cont'd)		B = CsOH (39)	
$-t$	ϵ	$-t$	ϵ	$-t$	ϵ
5% B				2.85% B	
130	209	170	195	140	3.32
150	204	180	176	170	2.80
160	201	184	139	190	2.76
		188	80.0		

Alcoholic Solution; Solvent = C_2H_6O; B = KOH (67)

5% B	$-t=$	170	175	180	185	190
	$\epsilon=$	4.00	3.13	2.82	2.70	2.62

TABLE 11.—DIELECTRIC CONSTANT (ϵ) OF COLLOIDAL SUSPENSIONS IN WATER

Frequency of emf = $\nu = A \times 10^n$ cycle/sec; concentration = C, unit of C = 1 gram per 100 kg of mixture = 1 g per 10^5 g; centigrade temperature. For Au, S, Al_2O_3, Bi_2O_3, CuO, $CuCO_3$, Fe_2O_3, PbO, *v.* (39).

V_2O_5 (59)

A	n	ϵ	A	n	ϵ	t	ϵ
C = 0.75; 19°C			C = 8; 20.0°C (57)			C = 49; A = 6.82; n = 5 (56)	
2.5	3	131	5.45	4	720	20.0	127.7
5.0	3	131	6.7	4	610	30.0	85.9
6.0	3	130	8.57	4	450	45.0	81.3
7.5	3	126	1.2	5	304		
1.5	4	113	3	5	155		
						A | n	ϵ
C = 3; 19°C			C = 32; 20°C (57)			C = 120; 20.0°C (57)	
1.5	3	335	3	5	225		
1.875	3	350	3.75	5	180	3.0	5 390
2.5	3	355	6.0	5	125	3.75	5 306
3.0	3	350	1	6	94	6.0	5 187
5.0	3	340				1	6 125
1.5	4	257	t	ϵ			
C = 6; 19°C			C = 32; A = 6.00; n = 5 (57)			t | ϵ	
2.5	3	527	20.0	146		C = 120; A = 6.0; n = 5 (57)	
3.75	3	569	40.0	115		30.0	172
5.0	3	550	50.0	95.5		40.0	126
7.5	3	505	60.0	78.0		50.0	102
1.5	4	410	70.0	75.0		60.0	78.4

TABLE 12.—DIELECTRIC CONSTANT (ϵ) OF MISCELLANEOUS MATERIALS

	ϵ	Lit.
Basalt*	12	(120)
Diorite*	8 to 9	(120)
Granite*	7 to 9	(120)
Loam (dry)†	3.5	(200)
Melaphyre*	13	(120)
Sand (dry)†	2.5	(200)
Sand (15% H_2O)†	*ca.* 9	(200)
Sandstone*	9 to 11	(120)
Sidot blende‡		
In dark	7.2	
Illuminated	14.4	
Soil (dry)§†	1.9	(200)
Soil (19% H_2O)§†	*ca.* 8	(200)

* Dried in desiccator for 10 hr.

† Observations made at radio frequency.

‡ Phosphorescent ZnS, contains Cu (<0.01 % Cu). For variation of ϵ with intensity and wave-length of illumination, *see* (78); with frequency of emf, *see* Molthan, *Zeits. f. Physik*, **4**: 262; 1921. **5**: 284; 1921; with temperature and with phosphorescence, *see* Wilde, *Zeits. f. Physik*, **15**: 350; 1923.

§ "Garden soil."

TABLE 13.—VARIATION OF DIELECTRIC CONSTANT (ϵ) WITH PRESSURE: PURE ORGANIC LIQUIDS AND SOLID C_6H_6

$\epsilon_p = \epsilon_0(1 + ap \times 10^{-4} + bp^2 \times 10^{-8})$ if $1 < p < p_m$; $\epsilon_p = \epsilon_0(1 + 0.01\Delta p)$ where p has the value given in the table. ϵ_0 = value of ϵ at 20°C and 1 atmosphere, ϵ_p is its value at 20°C and a pressure of p + 1 atm. For values of ϵ_0, *see* Table 4. Unit of p, p_m = 1 normal atmosphere.

		p	Δp	a	b	p_m	Lit.
CCl_4	Carbon tetrachloride			0.72	− 4	60	(75.1)
		100	0.67				(68.1)
		300	1.93				(68.1)
		500	3.04				(68.1)
		800	4.47	0.68	− 1.5	800	(68.1)
$CHCl_3$	Chloroform			1.00	− 5	58	(75.1)
		500	4.95	1.120	− 2.6	500	(136)
CH_4O	Methyl alcohol	200	2.03				(64)
C_2H_6O	Ethyl alcohol, 99.8 %	200	2.01				(64)
C_3H_6O	Acetone	200	2.99				(64)
$C_4H_{10}O$	Ether			2.374	−19	60	(75.1)
		500	9.39	2.260	− 7.62	500	(136)
$C_5H_{12}O$	Amyl alcohol	100	0.42				(145)
		300	1.27				(145)
C_6H_5Br	Bromobenzene			0.620	0	60	(75.1)
$C_6H_5NO_2$	Nitrobenzene			0.640	0	56	(75.1)
C_6H_6	Benzene	100	0.596	0.645	− 5.0	120	(188)
		100	0.528				(68.1)
		300	1.48				(68.1)
		500	2.38				(68.1)
		500	2.66	0.623	− 1.75	500	(136)
		700	3.08	0.55	− 1.4	700	(68.1)
	(solid, 11°C)	>300		0.34	0	850	(68.1)
C_6H_7N	Aniline	100	0.45				(145)
		300	1.35				(145)
C_6H_{14}	Hexane	100	0.806	0.890	− 8.38	120	(188)
		100	0.77				(68.1)
		300	2.17				(68.1)
		500	3.37				(68.1)
		800	4.80	0.79	− 2.4	800	(68.1)
$C_7H_7NO_2$	*o*-Nitrotoluene			0.667	0	60	(75.1)
C_7H_8	Toluene			0.608	− 2	60	(75.1)
		500	2.81	0.614	− 1.05	500	(136)
C_7H_{16}	Heptane	100	0.72				(68.1)
		300	2.01				(68.1)
		500	3.09				(68.1)
		800	4.30	0.74	− 2.5	800	(68.1)
C_8H_{10}	*m*-Xylene	500	2.65	0.651	− 2.39	500	(136)

TABLE 14.—EFFECT OF MAGNETIC FIELD (H) UPON THE DIELECTRIC CONSTANT (ϵ) (94)

In general, ϵ is independent of H; but for certain liquid crystals, changes have been observed. The available data are given in this table. $\|[\perp]$ denotes that the direction of H is parallel [perpendicular] to the direction of the electrical field used to determine ϵ; ϵ_0 = value of ϵ when $H = 0$. $\epsilon_H = \epsilon_0(1 + 0.01\Delta)$. Unit of H = 1 kilogauss = 1000 cgsm unit; of ϵ = 1 cgse unit.

Substance		t	H	$-\Delta_\parallel$	ϵ_0
	Liquid air		11.0	<0.1	1.47
$CHCl_3$	Chloroform	20°	25.0	<0.03	5.14
$(C_2H_5)_2O$	Ethyl ether	20°	25.0	<0.03	4.36
$C_6H_5NO_2$	Nitrobenzene	20°	25.0	<0.016	35.6
C_6H_6	Benzene	20°	25.0	<0.06	2.28
$C_6H_5NH_2$	Aniline	20°	25.0	<0.02	7.13

$C_{14}H_{14}N_2O_3$, *p*-Azoxyanisole (liquid crystal) ϵ_0 = 6.9

H	$-\Delta_\parallel$	$-\Delta_\parallel$	$-\Delta_\perp$
	122°	135°	122°
0.30	1.4		
0.50	2.0	0.0	
1.00	2.2		
2.00	2.7	0.2	
4.00	2.8	0.3	0.0
7.35	2.8	0.3	

$C_{16}H_{18}N_2O_3$, *p*-Azoxyphenetole (liquid crystal) ϵ_0 = 6.8

H	$-\Delta_\parallel$	$-\Delta_\parallel$	$-\Delta_\perp$
	143°	154°	143°
0.15	0.4	0.0	
0.30	1.1		
0.50	3.0	2.2	
1.00	4.8	4.0	
2.00	5.0		
4.00	5.4	4.8	0.0
7.35	5.7	4.9	

Table 15.—Effect of Electric Field (E) upon the Dielectric Constant (ϵ) (84, 144)

Data bearing upon this effect are discordant and of doubtful value

$$\epsilon_{E_1} = 4\pi\left(\frac{\partial D}{\partial E}\right)_{E=E_1}, \text{ and } \epsilon_0 = 4\pi\left(\frac{\partial D}{\partial E}\right)_{E=0}$$

Unit of $\nu = 1$ cycle/sec; of $E = 1$ cgse unit; of ϵ_{E_1}, $\epsilon_0 = 1$ cgse unit. Centigrade temperature.

	t	ν	E_1	$\epsilon_0 - \epsilon_{E_1}$	Lit.
$C_5H_{11}OH + C_6H_6$*.....	19°	3000	20	0.018	(144)
$\epsilon_0 = 3.089$		3000	30	0.047	(144)
		10^6	160	$<1 \times 10^{-6}$	(84)
$(C_2H_5)_2O$, Ether.....	20°	10^6	100	7×10^{-6}	(84)

* Solution of n-amyl alcohol ($C_5H_{11}OH$) in benzene (C_6H_6); concentration = 20 vol. % of $C_5H_{11}OH$.

Table 16.—Dielectric Strength (S) of Pure Organic Substances

The dielectric strength (S) of a substance is defined as the minimum value of the electrical field intensity, in the substance, which will cause a disruptive electric discharge.

Whether it can be regarded as a constant, characteristic of the substance, is doubtful; it appears to vary with the nature of the electrodes, and with the sparking distance. If the distance is very short as compared with the radii of curvature of the faces of the electrodes, the field is essentially uniform and $S = V_s/l$, where V_s is sparking potential corresponding to the distance l. For greater distances, the field is not uniform and S is the maximum value of the field intensity. The available data are given in this table; probably all are uncertain by at least ±5%. Unit of $l = 1$ mm = 0.1 cm; of $V_s = 1$ volt; of $S = 10^6$ volt/cm.

Formula	Substance		l	V_s	S	Lit.
C_5H_{12}	Pentane.....	A*	0.001	110	1.10	(169)
			0.002	220	1.10	(169)
			0.003	330	1.10	(169)
C_6H_{14}	Hexane.....	A*	0.001	62	0.62	(169)
			0.002	195	0.98	(169)
			0.0025	316	1.26	(169)
C_7H_{16}	Heptane.....	A*	0.001	100	1.00	(169)
			0.002	186	0.93	(169)
			0.003	300	1.00	(169)
C_8H_{18}	Octane.....	A*	0.001	96	0.96	(169)
			0.002	190	0.95	(169)
			0.003	285	0.95	(169)
C_6H_6	Benzene.....	B*	0.5	32 500	0.65	(4)
$C_6H_4(CH_3)_2$	*o*-Xylene.....	B*	0.3	24 000	0.80	(4)
			0.4	28 100	0.70	(4)
			0.5	32 000	0.64	(4)
			0.6	36 100	0.60	(4)
		C*	0.2	22 200	1.11	(4)
			0.3	28 500	1.05	(4)
			0.4	34 800	1.01	(4)
			0.5	41 000	0.97	(4)
$C_6H_5NH_2$	Aniline 5%, in benzene.....	B*	0.45	29 000	0.64	(4)

* A = Electrodes of iridio-platinum; one flat, one spherical, radius great. B = Electrodes are brass spheres, diameter = 2 cm. C = Electrodes are brass spheres, diameter = 0.2 cm.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abegg, *8*, **60**: 54; 97. (2) Abegg and Seitz, *7*, **29**: 242; 99. (3) Abegg and Seitz, *7*, **29**: 491; 99. (4) Almy, *8*, **1**: 508; 00. (5) Andersin and Hirn, *60*, **51**: No. 11; 08. (6) Angervo and Liiri, *60*, **56**: No. 9; 13. (7) Arons, *8*, **53**: 95; 94. (8) Arons and Rubens, *8*, **42**: 581; 91. **44**: 206; 91. (9) Augustin, *Diss.*, Leipzig, 1898.

(10) Bädeker, *7*, **36**: 306; 01. (11) v. Baeyer, *8*, **17**: 30; 05. (12) Beaulard, *34*, **141**: 656; 05. (13) Beaulard, *51*, **5**: 165; 06. (14) Beaulard, *34*, **151**: 55; 10. (15) Beaulard and Maury, *51*, **9**: 39; 10. (16) Bergholm, *8*, **53**: 169; 17. (17) Bergholm, *8*, **65**: 128; 21. (18) Blake and Sheard, *2*, **15**: 148; 20. (19) Blüh, *96*, **25**: 220; 24.

(20) Bock, *96*, **31**: 534; 25. (21) Boltzmann, *75*, **68 II**: 81; 73. (21.1) Boltzmann, *8*, **155**: 403; 75. *75*, **69**: 795; 74. (22) Borel, *34*, **116**: 1509; 93. *149*, **30**: 131, 181, 219, 327, 422; 93. (23) Bouty, *34*, **114**: 1421; 92. (24) Bouty, *6*, **27**: 62; 92. (25) Braun, *63*, **5**: 199; 04. (26) Bryan, *2*, **22**: 399; 23. (27) Cassie, *62*, **181**: 1; 91. (28) Cauwood and Turner, *4*, **107**: 276; 15. (29) Clayton, *33*, **15**: 504; 16.

(30) Cohn and Arons, *8*, **28**: 454; 86. (31) Cohn and Arons, *8*, **33**: 13; 88. (32) Cole, *8*, **57**: 290; 96. (33) Colley, *63*, **10**: 329, 471, 657; 09. (34) Colley, *63*, **11**: 324; 10. (35) Coolidge, *8*, **69**: 125; 99. (36) Curie, *6*, **17**: 385; 89. (37) Dewar and Fleming, *5*, **61**: 2; 97. (38) Dewar and Fleming, *5*, **61**: 358; 97. (39) Dewar and Fleming, *5*, **61**: 368, 380; 97.

(40) Dobroserdov, *53*, **41**: 1164; 09. (41) Dobroserdov, *53*, **43**: 73, 225, 454; 11. (42) Dobroserdov, *53*, **44**: 396, 679; 12. (43) Drude, *8*, **55**: 633; 95. (44) Drude, *8*, **58**: 1; 96. (45) Drude, *8*, **59**: 17; 96. (46) Drude, *8*, **60**: 1; 97. (47) Drude, *8*, **60**: 500; 97. (48) Drude, *8*, **61**: 466; 97. (49) Drude, *7*, **23**: 267; 97.

(50) Drude, *8*, **64**: 131; 98. (51) Drude, *8*, **8**: 336; 02. (52) Dubbert and Schmidt, *in* Voigt, *Lehrbuch der Krystallphysik*, p. 459. Leipzig, Teubner, 1910. (53) Eckert, *88*, **15**: 307; 13. (54) Eggers, *50*, **8**: 14; 04. (55) Ehrenhaft, *75*, **111 IIa**: 1549; 02. (56) Errera, *55*, **31**: 59; 22. (57) Errera, *55*, **32**: 157; 23. (58) Errera, *55*, **32**: 240; 23. (59) Errera, *55*, **32**: 373; 23.

(60) Errera, *51*, **3**: 401; 22. (61) Errera, *51*, **4**: 225; 23. (61.1) Errera and Lepingle, *186*, **2**: 150; 25. (62) Eversheim, *8*, **8**: 539; 02. (63) Eversheim, *8*, **13**: 492; 04. (64) Falckenberg, *8*, **61**: 145; 20. (65) Fellinger, *8*, **7**: 333; 02. (66) Fellinger, *8*, **60**: 181; 19. (67) Fleming and Dewar, *5*, **61**: 299; 97. (68) Fleming and Dewar, *5*, **61**: 316; 97. (68.1) Francke, *8*, **77**: 159; 25. (69) Franke, *8*, **50**: 163; 93.

(70) Frayne, *2*, **21**: 348; 23. (71) Fürth, *96*, **22**: 98; 24. (72) Fürth, *8*, **70**: 63; 22. (73) Gouy, *34*, **106**: 540; 88. (74) Gouy, *34*, **106**: 930; 88. (75) Graffunder, *8*, **70**: 225; 23. (75.1) Grenacher, *8*, **77**: 138; 25. (76) Grimm and Patrick, *1*, **45**: 2794; 23. (77) Grützmacher, *96*, **28**: 342; 24. (78) Gudden and Pohl, *96*, **1**: 365; 20. (79) Gutton, *34*, **158**: 621; 14.

(80) Harrington, *2*, **8**: 581; 16. (80.1) Harris, *4*, **127**: 1049; 25. (81) Hattwich, *75*, **117 IIa**: 903; 08. (82) Heerwagen, *8*, **48**: 35; 93. (83) Heinke, *101*, **17**: 483, 499; 96. (84) Herweg, *96*, **3**: 36; 20. (85) Hopkinson and Wilson, *62*, **189**: 109; 97. (86) Hyslop and Carman, *2*, **15**: 243; 20. (87) Isnardi, *96*, **9**: 153; 22. (88) Isnardi and Gans, *63*, **22**: 230; 21. (89) Jackson, *3*, **43**: 481; 22.

(90) Jaeger, *8*, **53**: 409; 17. (91) Jahn and Moller, *7*, **13**: 385; 94. (92) Jezewski, *51*, **3**: 293; 22. (93) Jezewski, *165*, **1920**: 88. (94) Jezewski, *51*, **5**: 59; 24. (95) Joachim, *8*, **60**: 570; 19. (96) Jokela and Valanto, *60*, **54**: No. 18; 12. (97) Jona, *63*, **20**: 14; 19. (98) Kahlenberg, *78*, **7**: 167; 05. (99) Kahlenberg and Anthony, *42*, **4**: 358; 06.

(100) Karki and Suikkanen, *60*, **54**: No. 19; 12. (101) Katayama and Tomiyama, *41*, **36**: 745; 15; *10*, **4**: 641; 22. (102) Keller, *55*, **26**: 173; 20. (103) Keller, *55*, **27**: 255; 20. (104) Keller, *55*, **29**: 193; 21. (105) King and Patrick, *1*, **43**: 1835; 21. (106) Klein, *147*, **3**: No. 24; 18. (107) Klemenčič, *75*, **91 II**: 712; 85. (108) Kossonogoff, *63*, **3**: 207; 02. (109) Lampa, *8*, **61**: 79; 97.

(110) Landolt and Jahn, *7*, **10**: 289; 92. (111) von Lang, *75*, **105 IIa**: 253; 96. **104 IIa**: 980; 95. (111.1) Lange, *96*, **33**: 169; 25. (112) Lattey, *3*, **41**: 829; 21. (113) Lebedev, *8*, **44**: 288; 91. (114) Liebisch and Rubens, *76*, **1919**: 876. (115) Liebisch and Rubens, *76*, **1921**: 211. (116) Linebarger, *7*, **20**: 131; 96. (117) Linnitschenko, *63*, **14**: 543; 13. (118) Lippmann, *Diss.*, Leipzig, 1912. (119) Löwe, *8*, **66**: 390, 582; 98.

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(140) Philip and Haynes, *4*, **87**: 998; 05. (141) v. Pirani, *Diss.*, Berlin, 1903. (142) Pohrt, *8*, **42**: 569; 13. (143) Potapenko, *96*, **20**: 21; 23. (144) Ratnowsky, *88*, **15**: 497; 13. (145) Ratz, *7*, **19**: 94; 96. (146) Richards, *2*, **22**: 122; 23. (147) Richards and Shipley, *1*, **41**, 2002; 19. (148) Richardson, *5*, **92**: 41; 16. (148.1) Riegger, *8*, **59**: 753; 19. (149) Roberts, *2*, **12**: 50; 01.

(150) Röntgen, *8*, **52**: 593; 94. (151) Romanoff, *8*, **40**: 281; 13. (152) Romich and Nowak, *75*, **70 II**: 380; 75. (153) Rosa, *3*, **31**: 188; 91. (154) Roy, *Diss.*, Jena, 1910. (155) Rubens, *76*, **1915 I**: 4. (156) Rubens, *76*, **1917**: 556. (157) Rubens, *96*, **1**: 11; 20. (158) Rubens and Nichols, *8*, **60**: 418; 97. (159) Rudolfi, *7*, **66**: 705; 09.

(160) Rudolph, *Diss.*, Leipzig, 1911. (160.1) Sänger, *63*, **27**: 556; 26. (161) Salazer, *132*, **22**: 275; 24. (161.1) Sayce and Briscoe, *4*, **127**: 315; 25. (161.2) Sayce and Briscoe, *4*, **1926**: 2623. (162) Schaefer and Schlundt, *50*, **13**: 669; 09. (163) Schlundt, *50*, **5**: 157; 01. (164) Schlundt, *50*, **5**: 503; 01. (165) Schmidt, *8*, **7**: 142; 02. (166) Schmidt, *8*, **9**: 919; 02. (167) Schmidt, *8*, **11**: 114; 03. (168) Schulze, *9*, **18**: 77; 12. (169) Shaw, *3*, **12**: 317; 06. (170) Siivola, *426*, **1922**: No. 18. (171) Silberstein, *8*, **56**: 661; 95. (172) Smale, *8*, **57**: 215; 96. (173) Smale, *8*, **60**: 625; 97. (173.1) Smyth and Zahn, *1*, **47**: 2501; 25. (174) Speyers, *12*, **16**: 61; 03. (175) Starke, *8*, **60**: 629; 97. (176) Stewart, *4*, **93**: 1059; 08. (177) Tangl, *8*, **10**: 748; 03. (178) Tangl, *8*, **23**: 559; 07. (179) Tangl, *8*, **26**: 59; 08.

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HIGH VOLTAGE CORONA

J. B. Whitehead

Introduction.—With alternating voltage the corona first appears at the crest of the voltage wave. For oscillographic study of effect of corona on current wave, *v.* (2). The formation of corona in a closed cylindrical tube is followed by a rise in pressure; Kunz (13), Warner (34), and Fazel (8) ascribe this to generation of new ions; Arnold (1) and Tyndall (33) ascribe it to a rise in temperature. Corona phenomenon finds a practical application in the corona voltmeter (43) for measuring high voltages; the corona rod and coaxial cylinder are enclosed in an airtight casing in which the pressure may be varied so as to extend the range; corona formation is indicated by ionization current or by sound in telephone; accuracy is 0.5%.

Symbols.—E_{mc} = maximum electric field (potential gradient) at surface of conductor when corona first appears; k = empirical constant; p = pressure, r = radius of conductor, s = distance between centers of adjacent conductors, t = temperature (°C), $V_{ec}[V_{mc}]$ = effective [maximum] potential of conductor above neutral when corona first appears, V_e = effective potential of conductor above neutral, W_{lc} = power loss due to corona, δ = ratio of density of air to its value at 25°C and 1 atmosphere (if unit of p =1 cm of Hg, $\delta = 3.92p/(273 + t)$), ν = frequency.

General Relations.—For round wires in air $E_{mc} = A\delta + B\sqrt{\delta/r}$; A and B depend somewhat upon frequency (*v.* Tables 1, 2). For He, H, O, and N, Lee and Kurrelmeyer find $E_{mc} = Ap + B\sqrt{p}$ if 4 cm Hg $\leq p \leq$ 30 cm Hg; A and B depend upon the gas (13.1).

For transmission lines and cables (23), $V_{mc} = k\delta E_{mc} r \log_e(s/r)$; for smooth wires, $k = 1$; for weathered wires, $k = 0.98$ to 0.93; for 7-strand cables, $k = 0.87$ to 0.83. For power loss Peek (16, 17, 20) proposes the empirical relation: $W_l = 241/\delta(\nu + 25)\sqrt{r/s} \times (V_e - V_{mc})^2 \times 10^{-5}$ watt per meter, where unit of ν = 1 cycle/sec, of V_e, V_{mc} = 1 kilovolt. This relation does not accord with observations if $(V_e - V_{mc})$ is small. For greater values, up to 280 kilovolt, it accords closely with Peek's observations (19), and approximately with the observations of Faccioli (6), Mershon (15), Hendricks (11), Harding (10), Lewis (14), and Wood (45, 46), but unpublished observations by Harding, up to 500 kilovolt, indicate considerable discordance.

Table 1.—Corona on Clean, Round Wires in Air, 25°C and 1 Normal Atmosphere—Variation with Radius

For continuous (D.C.) voltage, subscripts (+, −) indicate the sign of the potential of the wire around which the corona appears. E_{mc}, E_+, E_- are independent of the material of the wire and of the humidity (37) of the air. E_{mc} decreases as ν increases; at ν = 90 it is 2.4% less than at ν = 20 (43); at ν = 2 000 it is 6% less than at ν = 60 (42); Peek (20) reports no change below ν = 1 000, and a small decrease from ν = 1 000 to ν = 30 000. Probable accuracy is indicated in "Lit." column. For variation with density of air, *v.* Table 2. Unit of ν = 1 cycle/sec; of r = 1 cm = 0.394 in.; of E_{mc}, E_+, E_- = 1 kilovolt cm^{-1} = 3.335 cgse cm^{-1} = 254 kilovolt in^{-1}.

ν = 60 cycle/sec			ν = 0 (D.C.) (7, 22, 29, 30, 40, 44)		
r	E_{mc}	Lit.	r	E_+	E_-
0.01	120	(16)*	0.002	239	221
.025	86.5	3%	.003	198	187
0.05	71.36		.004	174	166
.06	67.86		.005	156	150
.07	65.10		.006	144	140
.08	63.24	(37, 38, 39, 41, 43)†	.007	134	132
.09	61.48		.008	126	125
.10	60.04		.009	121	120
.20	52.10	0.8%	.01	116	116
.30	47.99		.02	93	95
.40	45.56		.03	82.5	85
.50	43.89		.04	76	79
.60	42.68		.05	71	74
0.70	41.72		.06	67.5	70.5
.80	41		.07	64.5	67.5
.90	40	(26)‡	.08	62.5	66.0
1.0	39.5		.09	60	64
2.0	35.8		.10	58	62
3.0	34.2	2% to 3%	.130	56.9	
4.0	33.0		.239	51.3	
5.0	32.5		.625	43	
6.0	32.1		1.110	40.6	
7.0	31.7				
8.0	31.4	(31)§			
9.0	31.1				
10.0	30.8				
12.5	30.3	2% to 3%			
15	30				

* Peek: Parallel wires, high voltage by ratio transformation.

† Whitehead and coworkers: Concentric cylinders. High voltage is measured directly.

‡ Petersen: Concentric cylinders. Sparkover and corona.

§ Schumann: Concentric cylinders. Voltage by ratio transformation. Corona and sparkover.

TABLE 2.—CORONA ON ROUND WIRES IN AIR: VARIATION WITH DENSITY

There is general agreement that the equation $E_{mc} = A\delta + B\sqrt{\delta/r}$ accords with the observations with alternating voltages of fixed ν over a wide range of t, p, and r; and accords with observations with continuous voltages if $p > 10$ cm Hg and $r > 0.004$ cm. For D.C. data for smaller wires and lower pressures than those in table, and for current flow at $E > E_{mc}$, *v.* (7, 30). Values in columns δ, r, p, and t indicate the limiting values covered by the observations. Except as indicated the electrodes were coaxial cylinders. Unit of $E_{mc} = 1$ kilovolt cm^{-1} = 3.335 cgse cm^{-1}; of $r = 1$ cm; of $p = 1$ cm of Hg; of $t = 1$°C.

Alternating voltage, 60 cycle/sec

δ	A	B	r	p	t	Lit.
0.47; 1.34	31.6	9.41	0.044; 0.237	36; 102	7; 41	(37, 38)
1.0; 1.13	29.8*	8.96*	0.01; 0.5	74; 76	−13; 22	(16)
0.7; 1.2	31	9.55	0.059; 0.953	75.5	−20; 140	(17)
0.02; 1	31	9.55	0.12; 0.25	1.7; 75	18; 24	(18)
<2.295	29.84	9.90	0.05; 0.63	25; 139	18; 26.7	(43)
>2.295	32.96	8.56				
1.016	27.5†	12.05†	0.05; 5.0	76	20	(26)
1.016	25.2†	19.15†	1.5; 5.96	76	20	(31)
1.016	33.7	8.9	0.037; 0.116	76	20	(40)

Continuous voltage

δ	A_+	A_-	B_+	B_-	r	p	t	Lit.
0.07; 1.0		31		9.54	0.04	5.3; 76	25	(7)
1	33.7	31	8.13	9.54	0.037; 0.116	76	25	(40)
0.11; 1.0	39.8	40.2	7.32	8.41	0.026; 0.046	10; 70	6; 70	(44)
0.075; 1.0	31	31	9.55	9.55	0.057; 0.239			(22)

* Parallel wires in free air.

† Computed by J. B. W. For (26) there was a sparkover, but no corona; for (31) there were both sparkover and corona.

TABLE 3.—EFFECTIVE CORONA VOLTAGE (V_{ec}) FOR THREE-PHASE TRANSMISSION LINES IN TRIANGULAR ARRANGEMENT: 25°C, 1 NORMAL ATMOSPHERE

Corona causes an increase in electrostatic capacity of line, and in 3-phase, Y-connected grounded systems, causes a triple harmonic in the neutral; in ungrounded systems, distortion of voltage may result (24). Surface irregularities of transmission conductors reduce the corona-forming voltage. Peek (23) gives the following general equation: $V_{ec}\sqrt{2} = V_{mc} = k\delta E_{mc} r \log_e(s/r)$.

For symbols and values of k, *see* above. At 25°C and an altitude of H meter above sea-level, $\delta = 1 - \Delta$, where $1/\Delta = 0.5 + 8730/H$, approximately (*cf.* eq. 4, Vol. I, p. 71).

If all wires are in same plane, V_{ec} for central wire will be 4% lower, and for outer wires 6% higher than for triangular arrangement of same spacing. For parallel brass tubes, $2r = 2.54$ to 8.9 cm, $s = 465$ cm, $V_{ec} = 400$ to 990 kilovolt, Peek (25) reports agreement with the equation.

In first column of table the numbers 4 to 0000 refer to the Brown and Sharpe wire gage; 0.25 to 1.00 denote the sectional area as expressed in units of 10^6 circular mil = 5.067 cm^2. Values of s correspond to integral numbers of feet (from 4 to 20); 1 ft. = 30.5 cm. Unit of size = B. & S. wire gage, or 10^6 cir. mil; of r and $s = 1$ cm; of $V_{ec} = 1$ kilovolt.

s =		122	152	183	245	305	366	426	490	610
Size	2r	V_{ec} (stranded cables)								
4	0.584	56	58	60	62	64	66	68	69	71
3	0.663	62	65	67	70	72	74	76	77	80
2	0.736		71	73	76	79	81	83	85	87
1	0.839		79	81	85	88	91	93	95	97
0	0.950			90	95	98	102	104	108	109
00	1.07			98	104	108	111	114	117	121
000	1.19				114	118	121	124	127	132
0000	1.35				125	130	135	138	141	146
0.25	1.50				138	144	149	152	156	161
0.30	1.57					151	156	161	165	171
0.35	1.73					161	166	170	175	180
0.40	1.85					171	176	180	185	192
0.45	1.96					178	184	190	194	200
0.50	2.04					188	194	199	205	210
0.80	2.62						234	241	244	256
1.00	2.92						256	264	270	281
Size	2r	V_{ec} (wires)								
4	0.524	54*	56	58	60	62	64	65	66	68
3	0.581	59	62	64	66	68	70	72	74	76
2	0.655		69	70	74	76	78	80	82	84
1	0.734		75	77	81	83	86	88	90	92
0	0.826			85	89	92	95	97	99	102
00	0.928			94	98	102	105	107	110	113
000	1.04				109	113	116	119	121	124
0000	1.17				120	125	128	131	134	138

* For $s = 91$, $V_{ec} = 51$.

TABLE 4.—CORONA IN OIL

With coaxial cylindrical electrodes and alternating voltage, E_{mc} for pure, dry transil oil satisfies the following equation (21):

$$E_{mc} = 36(1 + c/\sqrt{r}) \text{ kilovolt/cm},$$

where $c^2 = 1.44$ cm. It changes only slightly with temperature between 10 and 100°C. Very slight traces of moisture (1 in 10 000) greatly reduce the sparkover and corona-forming voltages. Sparkover and corona are simultaneous if $R < 300r$. R = internal radius of outer cylinder.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Arnold, *2*, **9**: 93; 17. (2) Bennet, *129*, **32**: 1787; 13. (3) Crooker, *2*, **8**: 344; 16. (4) Davis, *129*, **33**: 589; 14. (5) Faccioli, *129*, **30**: 377; 11. (6) Faccioli, *129*, **30**: 88; 11. (7) Farwell, *129*, **33**: 1631; 14. (8) Fazel, *2*, **19**: 157; 22. (9) Görges, Weidig and Jaensch, *101*, **32**: 1071; 11.

(10) Harding, *129*, **31**: 1035; 12. (11) Hendricks, *129*, **30**: 115; 11. (12) Jakobsen, *129*, **37**: 91; 18. (13) Kunz, *2*, **8**: 28; 16. **19**: 165; 22. (13.1) Lee and Kurrelmeyer, *39*, **44**: 16; 25. (14) Lewis, *129*, **40**: 1079; 21. (15) Mershon, *129*, **27**: 846; 08. (16) Peek, *129*, **30**: 1889; 11. (17) Peek, *129*, **31**: 1051; 12. (18) Peek, *129*, **32**: 1767; 13. (19) Peek, *129*, **34**: 269; 15.

(20) Peek, *Dielectric phenomena in high voltage engineering*. New York, McGraw-Hill Book Co., 1915. (21) Peek, *120*, **18**: 821; 15. (22) Peek, *129*, **35**: 783; 16. (23) Peek, *107*, **76**: 1258; 20. (24) Peek, *129*, **40**: 1155; 21. (25) Peek, *120*, **25**: 111; 22. (26) Petersen, *Hochspannungstechnik*, p. 43. Stuttgart, Enke, 1911. (27) Ryan, *129*, **21**: 275; 02. **23**: 101; 04. (28) Ryan, *129*, **30**: 1; 11. (29) Schaffers, *63*, **14**: 981; 13.

(30) Schaffers, *63*, **15**: 405; 14. (31) Schumann, *125*, **11**: 1; 22. (32) Schumann, *Elektrische Durchbruchfeldstärke von Gasen*. Berlin, Springer, 1923. (33) Tyndall, *3*, **35**: 261; 18. (34) Warner and Kunz, *86*, **No. 114**; 19. (35) Weicker, *101*, **32**: 436, 460; 11. (36) West, *129*, **30**: 77; 11. (37) Whitehead, *129*, **29**: 1159; 10. (38) Whitehead, *129*, **30**: 1857; 11. (39) Whitehead, *129*, **31**: 1093; 12.

(40) Whitehead and Brown, *129*, **36**: 169; 17. (41) Whitehead and Fitch, *129*, **32**: 1737; 13. (42) Whitehead and Gorton, *129*, **33**: 951; 14. (43) Whitehead and Isshiki, *129*, **39**: 407; 20. (44) Whitehead and Lee, *129*, **40**: 1201; 21. (45) Wood, *107*, **79**: 277, 882; 22. (46) Wood, *129*, **41**: 711; 22.

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All metals above −80°C (except rare earth metals)

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LEONARD B. LOEB

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* Covering data prior to March, 1928. For complete survey of the subject and complete bibliography, *see* (110).

* Contient les données antérieures à mars 1928. Pour avoir une vue d'ensemble complète du sujet et pour la bibliographie complète, *voir* (110).

* Daten soweit wie sie bis einschliesslich Februar 1928 bekannt geworden sind. Für die vollständige Übersicht dieses Gegenstandes und die gesamte Literatur, *siehe* (110).

* Comprende i dati anteriori al marzo 1928. Per una conoscenza completa del soggetto e per una bibliografia completa, *vedi* (110).

INTRODUCTION

Types of Ions.—Three types of carriers may be distinguished: Normal ions, slow ions, and free electrons.

Normal ions are the carriers generally found in dry, dust-free gases at approximately atmospheric pressure. As far as is known (83, 97, 139), after the first few hundredths of a second they carry a single electronic charge (4.774×10^{-10} es). Their mass is not known, but is of the same order as that of one to several molecules; their exact nature is an object of controversy (67, 81, 82, 96, 126) but it is certain that in *some cases* they consist of two or more molecules. Where the mobility of the completely formed positive ion is markedly less than that of the negative ion the mobility of the newly formed positive ion is abnormally great (33, 35, 36, 37, 38, 39, 41, 79, 136, 149, 152) and probably equals that of the negative ion (40, 87). In these gases the positive carrier seems to be completely formed after 0.03 second, and then its mobility no longer varies with its age. For gases in which the negative ion is the less mobile, no data exist. The mobility of both ions appears to be remarkably independent of the mass of the initially ionized molecule (10, 38, 40, 41, 42, 49, 61, 67, 82, 100, 125, 153). In at least one case (40) this can be ascribed to a transfer of the charge from an ionized molecule of higher ionizing potential to one of a lower; in other cases, such as with radioactive ions (36, 39, 42), this is not so. The nature of the completely formed ion does not depend upon the process by which it was formed (38, 39, 41, 42, 49, 73) provided this process does not directly give rise to charged particles of more than molecular mass. It does however very much depend on the electrical and chemical nature of the surrounding gases with which it has had time to come into equilibrium (41, 81, 82, 96). In gases with a negative mobility higher than that of the positive, the mobility of the negative ion is independent of its age; abnormalities observed at low pressures are attributed to a delay in the attachment of the electrons to neutral molecules to form negative ions (50, 55, 56, 68, 69, 77, 97, 134, 155, 156); in some gases, an electron must make many collisions with molecules before attaching to one to form an ion (*see* Table 12). In certain pure gases [He, A (43), N_2, H_2 (68), CO (150) and probably NH_3] the electron cannot attach itself to a molecule to form an ion. In such cases the negative ions are formed by the attaching of the electrons to impurities which may be present; these negative ions have mobilities which are of the same order of magnitude as those of positive ions.

Slow ions consist of pre-existing nuclei, of more than molecular mass, to which normal ions have become attached (45, 112). Their mobilities appear to vary somewhat with age (8, 9, 18, 19, 20, 21, 22, 23, 45). Two definite types (107, 108, 112) of such

ions have been found in moist air. *Type I* is characterized by a mobility which decreases as the partial pressure of the water vapor is increased; these are not found when the partial pressure exceeds 17 mm of mercury (108). *Type II* (62, 63, 107), the so-called Langevin ion, is found at all humidities; and its mobility depends, not upon the partial pressure, but upon the relative humidity, decreasing as the latter increases (8, 9, 18, 19, 20, 21, 22, 23, 90, 98, 99, 101, 102, 103, 145). Besides the ions included in these two types, there are other carriers formed by the attachment of normal ions to solid particles of various sizes; the mobilities of these vary with the size of the particles; these will be called *heterogeneous slow ions.*

Electrons.—The velocity (v) of migration of free electrons is not proportional to the intensity of the electric field causing the migration (4, 70, 71, 112, 139, 143, 144). Under the action of an impressed electric field, the velocity of thermal agitation of the electrons exceeds (139, 143, 144) that of the surrounding gas molecules by a factor (c) depending upon both the field strength (F) and the pressure (P) of the gas. Within the limits covered by observations, the values of c and of v at a specified temperature and for a given gas are quite closely determined by the ratio F/P. *See* Table 11. (For theoretical discussions, *see* (25, 26, 51)).

Coefficient of Recombination of Ions.—Our knowledge of the coefficient of recombination of ions in gases is in a highly unsatisfactory state. Beside difficulties due to columnar ionization in the case of ionization by α-particles (131), no matter what the source of ionization, the initial density and distribution of ions are not known, and erroneous assumptions in this regard may lead to values of the coefficient (α) which are seriously in error. Thus, Rümelin (120) and Plimpton (106) have found that, during a short interval immediately following the formation of the ions, α has an apparent value that is five times the corresponding value reported below (Tables 7, 8, 9). This may be due in part to an initial recombination of free electrons with + ions (84). Values obtained by the use of α-particles have been eliminated as far as possible from Tables 7, 8, and 9, later values obtained in other ways being given. Most observers find that at low pressures and room temperatures α increases nearly proportionally to P, but at pressures greater than 1 atm. it approaches a constant value. Data for variation with temperature are discordant; those of Erikson are probably the best, and indicate that α increases with the temperature.

Mobility (k).—The mobility of an ion = velocity of migration per unit electrical field intensity. Over a wide range of densities (d), kd is a constant for a given gas. (*See* Table 4.) Value of k at 0°C and 760 mm of mercury at 0°C, is often called the mobility constant = k_0. Uncertainties in the proper interpretation of the observations and slight variations in the experimental procedure (73, 74, 128, 146), as well as traces of unsuspected active impurities present in any one of a series of gases, may introduce variations of 20 to 30% in the inferred value of k, but relative values obtained under comparable conditions (41, 81, 96, 112, 139, 147) are quite accurate except for the selective action of impurities. For methods of measurement and interpretation of observations, *see* (24, 33, 45, 46, 49, 56, 57, 60, 73, 74, 112, 118, 128, 160). For attempts at establishing theoretical relations between k and other properties of the gas, *see* (45, 61, 67, 76, 82, 94, 112).

Effective Sectional Area of Molecule.—*See* p. 117.

TABLE 1.—MOBILITY CONSTANT OF NORMAL IONS IN GASES

For mixed gases other than air, *see* Table 2

Except as another is indicated, pressure = 760 mm of Hg, temperature = 15°C. Methods: B = air-blast, C = current measurement, F = Franck's, L = Langevin's, R = Rutherford's, T = Tyndall and Grindley's; F, R, and T are alternating current methods. Range in value is indicated by { ; el = negative carriers are free electrons; i = gas was slightly impure; p = gas was pure, giving free electrons even at high pressures. Mobility constant is $k_0 = kd/d_0$ where d_0 = density at 0°C and 760 mm of Hg and d = density when k was measured; excepting at the higher temperatures the values of k given below do not differ significantly from k_0. Data marked * have been reduced by dividing the observed values by 1.21 so as to bring them to the same basis as the others which were obtained by methods yielding a doubtful low value (*see* (73, 74, 128, 146)); it is believed that $k = 1.21M$ in all cases; subscripts (+, −) indicate the ion to which M refers. Unit of k = 1 cm sec^{-1} per volt cm^{-1} = 1 cm^2 volt^{-1} sec^{-1}.

Gas	M_+	M_-	Method	Lit.
Air	1.36	1.87	B	(160)
	1.37	1.80	F	(46)
	1.40	1.70	L	(60)
		1.70*	R	(56)
	1.36*	1.82*	F, p	(128)
	1.57*	2.02*		
		1.80*	F, R	(73)
		1.78*	T	(146)
A	1.37	1.70	F, i	(43)
	1.37	el	F, p	(43)
Cl_2		0.73	F	(148)
H_2	6.70	7.95	B, i	(160)
	5.33†	el	F, p	(88)
	6.02	7.68	F, i	(46)
	5.52	8.71	F, i	(158)
	5.34*	8.22*	F, i	(88)
	5.11	9.67	F, i	(156)
	4.96*	8.35*	F, i	(96)
He	5.09	6.31	F, i	(46)
	5.09	el	F, p	(45)
N_2	1.27	1.84	F, i	(44)
	1.27	el	F, p	(44)
	1.32	1.79	F, i	(158)
O_2	1.36	1.80	B	(160)
	1.29	1.79	F	(43)
CO		0.99*	R, p	(148)
	1.10	1.14	L	(154)
CO_2		1.02*	R, p	(72)
	0.76	0.81	B	(160)
	0.86	0.90	L	(60)
	0.83	1.02	L	(112†)
	0.73	1.07	F, p	(156)
	0.76	0.99	F	(112†)
CCl_4	0.30	0.31	L	(154)
H_2O	1.1	0.95	B, 100°	(110)
	0.77	0.73	B	(109)
	0.62	0.56	F	(86)
HCl	1.27‡		C	(123)
	0.65*	0.56*	F	(80)
NH_3	0.74	0.80	L	(154)
	0.62*	0.67*	F	(81)
		0.64*	R, p	(148)
N_2O	0.82	0.90	L	(154)
		1.10*	R	(72)
SO_2	0.415	0.414	F	(155)
	0.412	0.414	F	(159)
H_2S	0.59	0.57	F	(88)

Gas	Formula	M_+	M_-	Method	Lit.
Acetylene	C_2H_2		0.95*	R, p	(148)
		0.71*	0.77*	F, p	(87)
Benzene	C_6H_6	0.18	0.21	B	(109)
Ethane	C_2H_6		1.07*	R	(148)
Ethylene	C_2H_4		0.75*	R	(148)

TABLE 1.—(*Continued*)

Gas	Formula	M_+	M_-	Method	Lit.
n-Hexane	C_6H_{14}	0.15	0.16	*B*	(109)
n-Pentane	C_5H_{12}	0.36	0.35	*L*	(154)
		0.385	0.451	*F*	(159)
Chloroform	$CHCl_3$	0.19	0.16	*B*	(109)
Ethyl chloride	C_2H_5Cl	0.304	0.317	*F*	(159)
		0.33	0.31	*L*	(154)
Ethyl iodide	C_2H_5I	0.17	0.16	*L*	(154)
		0.181	0.181	*F*	(159)
Methyl bromide	CH_3Br	0.29	0.28	*L*	(154)
Methyl iodide	CH_3I	0.24	0.233	*F*	(155)
		0.216	0.226	*F*	(159)
Isobutyl alcohol	$C_4H_{10}O$	0.21	0.21	*B*, 105°	(110)
Ethyl alcohol	C_2H_6O	0.39	0.412	*F*	(155)
		0.363	0.373	*F*	(159)
Isoamyl alcohol	$C_5H_{12}O$	0.19	0.23	*B*, 130°	(110)
Methyl alcohol	CH_4O	0.37	0.38	*B*, 66°	(110)
		0.29	0.30	*B*	(109)
n-Propyl alcohol	C_3H_8O	0.22	0.22	*B*, 97°	(110)
Acetaldehyde	C_2H_4O	0.31	0.30	*L*	(154)
		0.307	0.331	*F*	(159)
Acetone	C_3H_6O	0.31	0.29	*L*	(154)
		0.236	0.247	*F*	(159)
Ethyl acetate	$C_4H_8O_2$	0.31	0.28	*L*	(154)
		0.16	0.19	*B*, 77°	(110)
		0.226	0.247	*F*	(159)
		0.19	0.24	*B*, 58°	(110)
Methyl acetate	$C_3H_6O_2$	0.33	0.36	*L*	(154)
n-Propyl acetate	$C_5H_{10}O_2$	0.15	0.17	*B*, 100°	(110)
Ethyl formate	$C_3H_6O_2$	0.30	0.31	*L*	(154)
Ethyl ether	$C_4H_{10}O$	0.29	0.31	*L*	(154)
		0.19	0.22	*F*	(79)
		0.15	0.16	*B*	(109)

* Observer's value is $k = 1.21M$. † Page 324. ‡ Sum of + and − mobilities.

TABLE 2.—MOBILITY (k) OF NORMAL IONS IN MIXED GASES

If p_a and p_b = the partial pressures of the constituents A and B of a binary mixture, $P = p_a + p_b$, $c_a = 100p_a/P$, and $c_b = 100p_b/P$, then c_a and c_b are the per cent concentrations of the two constituents. If k_a, k_b, k_{ab} are the mobilities for the pure gases and for the mixture, all reduced to 760 mm of Hg, then $k_{ab} = 100k_ak_b/(c_ak_b + c_bk_a)$ in the following cases: Both ions in $CO_2 + H_2$, and CO_2 + air (Blanc (10)), in $C_2H_2 + H_2$ (Loeb (87)), and in $O_2 + H_2$ (Mayer (96)); for + ions in $CH_3I + H_2$ (Wellisch (153)); and for − ions in $(C_2H_5)_2O + H_2$ (Loeb (81)). For both ions in NH_3 + air (Loeb (85)) and for + ions in $Cl_2 + H_2$ (Mayer (96)), $k_{ab} = k_ak_b/\sqrt{(c_ak_b^2 + c_bk_a^2)/100}$ fits the observations better. For all other mixtures yet studied, the data depart markedly from these laws if the concentration of the gas of lower mobility is small, but approximate one or other of them as this concentration is increased; *see also* (7, 61, 147). c_v = percentage of vapor. Unit of k = 1 cm²/(volt sec); of c = 1%; of P = 1 mm of Hg.

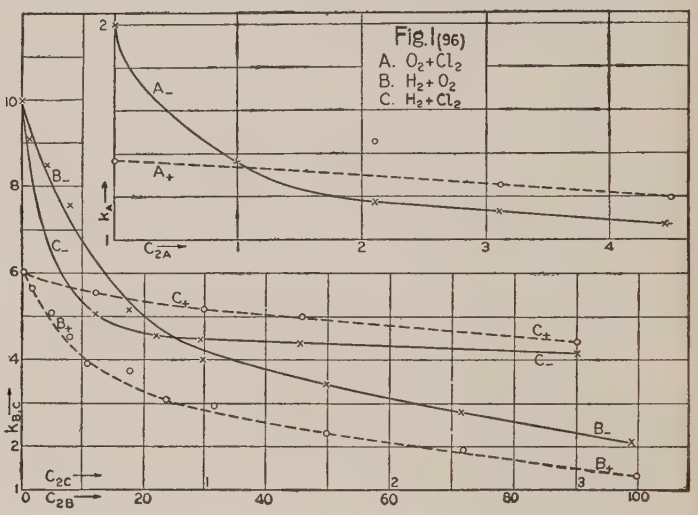
Air + vapor (*see also* Fig. Index)

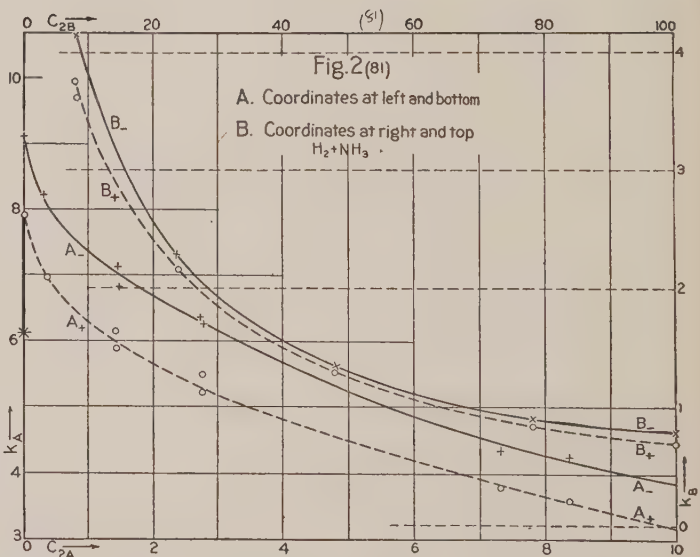
Vapor	c_v	k_+	k_-	P	t, °C	Lit.
None	0	1.37	1.80	737	15	(153)
H_2O*	0.0	1.38	2.11	566	25	(96)
	1.6	1.38	2.00	539	25	(96)
	2.4	1.35	1.85	535	26.5	(96)
	2.5	1.32	1.83	535	23	(96)
	3.0	1.25	1.63	522	23	(96)
CH_3I	0.81	1.37	1.80	737	15	(153)
C_2H_5Br	0.81	1.32	1.80	737	15	(153)
C_2H_5OH	1.32	0.91	1.10	755	15	(153)
C_3H_6O	1.19	1.15	1.37	755	15	(153)

* For H_2O, k has been reduced to basis of P = 760 mm.

Figure Index

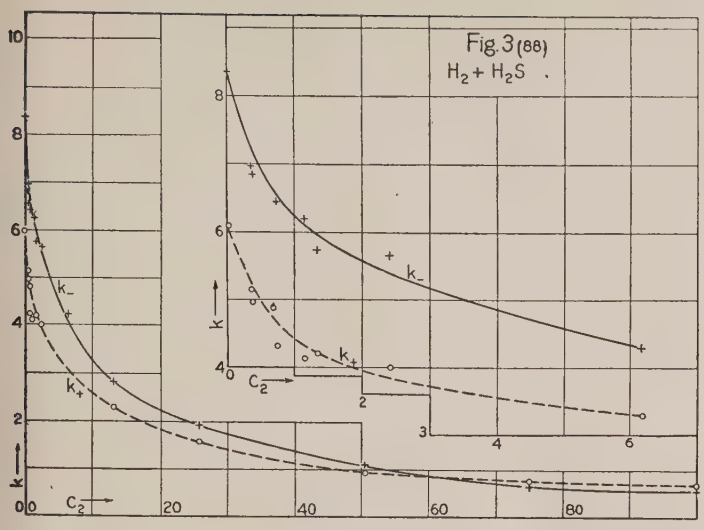
Mixture	Fig.	Mixture	Fig.
Air + H_2O	9	Air + *n*-$C_5H_{11}OH$	9
Air + HCl	7	$O_2 + H_2$	1
Air + NH_3	7	$O_2 + Cl_2$	1
Air + CO_2	6	$H_2 + Cl_2$	1
Air + CCl_4	8	$H_2 + H_2S$	3
Air + $CHCl_3$	8	$H_2 + NH_3$	2
Air + CH_3OH	9	$H_2 + CO_2$	6
Air + C_2H_5OH	9	$H_2 + (C_2H_5)_2O$	5
Air + *n*-C_3H_7OH	9	$H_2 + CH_3I$	4
Air + *n*-C_4H_9OH	9	$H_2 + C_2H_2$	4

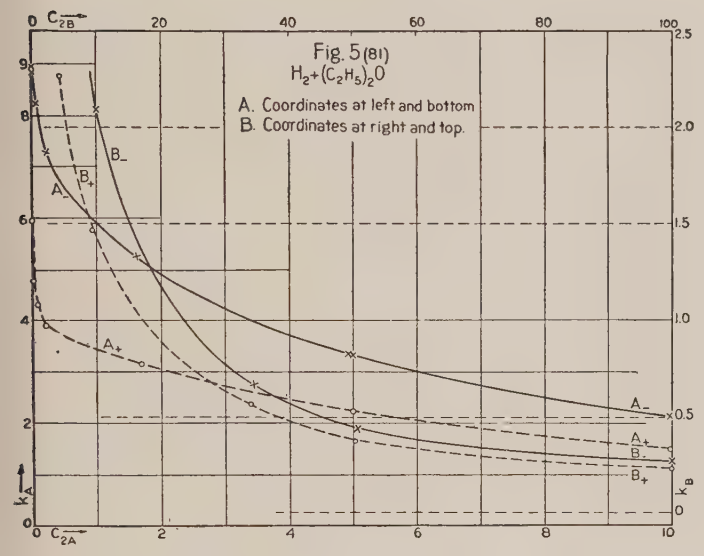


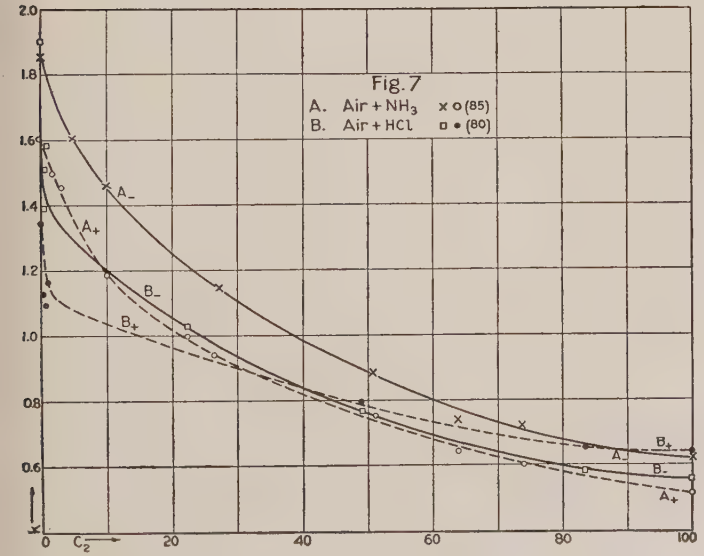


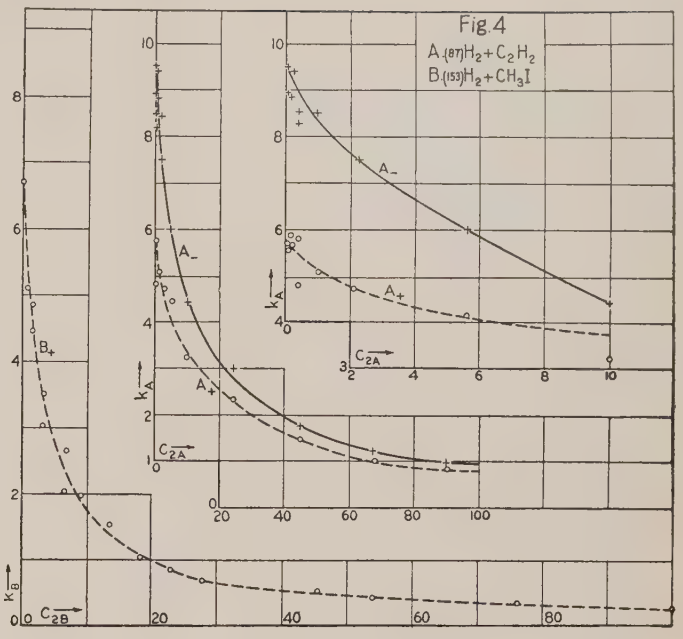
FIGS. 1 to 9.—Mobility (k) of normal ions in mixed gases.

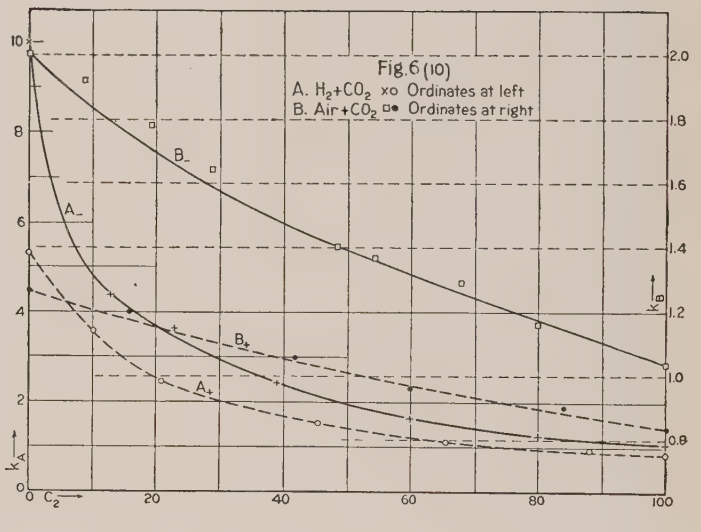
(For symbols and index, *see* Table 2.) P = 760 mm Hg, t = 15°C, C_2 = concentration of the second constituent; *e.g.* in Fig. 2, C_2 = concentration of NH_3; sign of ion is indicated by a subscript, + or −; literature reference is enclosed in ( ). Unit of C_2 = 1%; of k is nominally 1 cm²/(volt sec) but data are suitable for ratios only within the group of which they form a part.

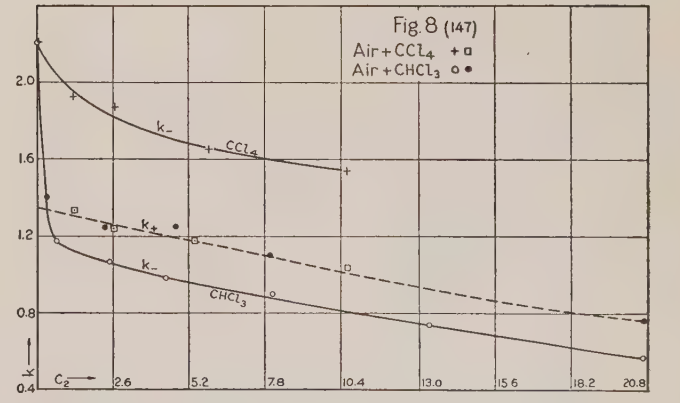












FIGS. 1 to 9.—Mobility (k) of normal ions in mixed gases.

(For symbols and index, *see* Table 2.) P = 760 mm Hg, t = 15°C, C_2 = concentration of the second constituent; *e.g.* in Fig. 2, C_2 = concentration of NH_3; sign of ion is indicated by a subscript, $_+$ or $_-$; literature reference is enclosed in ( ). Unit of C_2 = 1%; of k is nominally 1 cm²/(volt sec), but data are suitable for ratios only within the group of which they form a part.

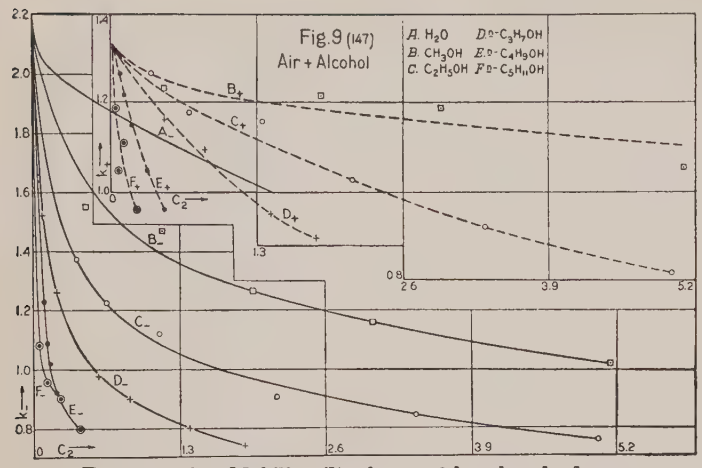


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TABLE 3.—MOBILITY (k) OF NORMAL IONS: VARIATION WITH PRESSURE (P)

For a given gas at a given temperature, Pk is a constant if P lies between a few mm of Hg and 75 or 100 atm. (**27, 57, 59, 92, 136, 149, 156**); at other pressures, variations are observed. At least a part of the variation at low pressures arises from the fact that an appreciable fraction of the ions present are not completely formed (**56, 97, 155, 156**) (*cf.* Table 5). Sign of ion is indicated by subscript + or −. Recent results in SO_2 indicate that for saturated vapors this law may not hold (**89**). Unit of k = 1 cm²/(volt sec); of P = 1 mm of Hg or 1 atm. Temperature = 15°C.

P	Pk_+	Pk_-	P	Pk_+	Pk_-	P	Pk_+	Pk_-
Air (**57**) P, atm.			Air (**92**).—(*Cont'd*)			CO_2*.—(*Cont'd*)		
13.3	1.32	1.84	155.04	1.68	2.21	0.93	1.30	
21.1	1.30	1.75	164.73	1.71	2.32	0.525	1.40	
31.2	1.35	1.87	175.40	1.61	2.19	0.507	1.50	
36.8	1.37	1.87	181.50	1.65	2.17	0.451	1.55	
41.7	1.32	1.87	O_2* (**136**) P, mm			0.350	1.65	
47.6	1.30	1.86	1.57	1.59		0.300	1.78	
50.6	1.32	1.85	1.39	1.86		0.210	1.70	
53.0	1.37	1.94	1.27	1.78		0.136	1.72	
59.5	1.34	1.89	1.06	1.99		0.091	2.22	
70.6	1.36	1.91	0.79	2.08		0.053	2.27	
74.6	1.39	1.96	0.63	2.09		H_2* (**136**) P, mm		
Air (**92**) P, atm.			0.48	2.48		3.54	6.32	
66.86	1.32	1.89	0.41	2.71		2.68	6.64	
87.21	1.41	1.86	0.25	2.60		1.50	6.40	
96.90	1.46	1.89	0.172	3.63		1.27	7.36	
108.50	1.48	2.04	0.151	2.96		0.99	8.00	
116.28	1.50	2.07	0.091	3.55		0.67	8.42	
123.10	1.52	2.05	CO_2* (**136**) P, mm			0.42	8.95	
132.75	1.60	2.04	1.47	1.09		0.38	9.60	
145.35	1.60	2.21	1.13	1.20				

* Thermions from hot salts.

TABLE 4.—MOBILITY (k) OF NORMAL IONS IN DRY AIR: VARIATIONS WITH TEMPERATURE (T)

At constant density and near room temperature, k is practically independent of T. For theoretical and other discussions, *see* (**45, 61, 76, 112, 128**). P = pressure; sign of ion is indicated by subscript + or −. Unit of k = 1 cm²/(volt sec). T = absolute temperature, °K; T_0 = value of T at 0°C.

TABLE 4.—(*Continued*)

T, °K	$(kT_0/T)_-$	T, °K	$(kT_0/T)_+$	$(kT_0/T)_-$	T, °K	k_+‡	k_-‡
P = 1 atm. (**56**)		P = 1 atm. (**104**)			Constant density* (**32**).—(*Cont'd*)		
698	2.19	411	1.33	1.66			
643	2.32	399	1.34	1.64	311	1.209	1.81
570	2.15	383	1.32	1.64	297	1.327	1.740
540	2.20	373	1.33	1.62	273	1.365	1.755
503	2.18	348	1.31	1.67	252	1.30	1.663
468	2.30	333	1.31	1.64			
463	2.20	285	1.33	1.71	Constant density (**31**)		
428	2.35	209	1.24	1.61			
416	2.27	94	0.682	0.68	T, °K	k_+	k_-
409	2.22				293	1.35	1.89
388	2.05	Constant density* (**32**)			209	1.34	1.82
378	2.00				93	1.20	1.24
360	2.00	T, °K	k_+†	k_-†			
340	2.10	336	1.207	1.729	Constant density§ (**128**)		
335	2.04	318	1.278	1.809			
300	1.91	306	1.326	1.777	T, °K	k_+‖	k_-‖
296	1.88	297	1.364	1.693	288	1.88	2.43
268	1.83	273	1.361	1.522	332	1.86	2.47
237	1.77	252	1.321	1.596	395	1.75	2.33
202	1.53	89	1.20	1.24	T, °K	k_+¶	k_-¶
180	1.32	T, °K	k_+‡	k_-‡	288	1.59	2.21
149	1.14	343	1.101	1.510	370	1.52	2.43
84.5	0.717	325	1.178	1.701	288	1.62	2.29

* The density is that corresponding to 0°C and 1 atm.
† Air dried over $CaCl_2$ and liquid air; vessel unheated.
‡ Air dried over liquid air; during filling, vessel heated to 373°K = 100C°.
§ The density is that corresponding to 15°C and 1 atm.
‖ Air of highest purity in contact with Na. ¶ Dry air of less purity.

TABLE 5.—MOBILITY (k) OF NEWLY FORMED IONS

Very new + ions have the same mobility as the − ions; mobility of − ions appears to be independent of age. Values of k on any one line of the table are relatively correct, but are not in all cases comparable with those on any other line.

U_n = upper limit for the age of the new ions; L_o = lower limit for the old ions. The same age limits apply to both + ions and − ions. Pressure = 760 mm of mercury; temperature = 15°C. Unit of U and L = 1 sec; of k = 1 cm²/(volt sec).

Gas	Carrier	Age limits		k_+		k_-		Lit.
		U_n	L_o	New	Old	New	Old	
Air	AcA and AcB	0.002	0.002	4.35	1.55			(**36**)
Air	ThA and ThB	0.002	0.002	4.35	1.55			(**39**)
Air	RaA and RaB	0.002	0.002	4.35	1.55			(**39**)
Air	C_2H_2	0.002	0.03	1.80	1.80	>*	>*	(**40**)
Air	A	0.005	0.013	1.80	1.36	1.80	1.80	(**37**)
Air	CO_2	0.005	0.02	1.80	1.36	1.80	1.80	(**35**)
Air†	Air	0.008	0.013	1.80	1.35	1.80	1.80	(**149**)
Air	H_2	0.008	0.013	1.80	1.36	>*	>*	(**37**)
Air	Pt	0.03	0.03	1.80	1.36	1.80	1.80	(**34, 38**)
Air	Air	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
Air	Air and C_2H_2	0.03	0.10	1.89	1.89	>*	>*	(**40**)
O_2	O_2	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
N_2	N_2	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
Air and NH_3	Air	0.06	0.06	1.89	1.89	1.89	1.89	(**41**)
He†	He	0.001	0.010	8.70	5.13			(**152**)
$(C_2H_5)_2O$†	$(C_2H_5)_2O$	0.005	0.02	0.22	0.19	0.22	0.22	(**79**)

* The > indicates that negative ion is slightly faster than initial positive ion. † Mobility of (k') measured at P = 5 to 50 mm and reduced to P = 760 mm by equation $k = k'P/760$.

Table 6.—Diffusivity (Δ) of Normal Ions

For methods of measurements and discussion of relation of Δ and k, *see* (47, 84, 97, 133, 139)

$\frac{dN}{dt} = -\Delta\frac{dn}{dz}dxdy$; dN = resultant number of ions, of the species considered, which diffuses, in the direction of increasing z, through the area $dxdy$ in the time dt, when the gradient of the concentration (n) of these ions normal to $dxdy$ is dn/dz; n = number per unit of volume. For these data, $P\Delta$ for a given gas and a given species of ion is essentially a constant; all observations were made near room temperature. At $P = A_n$, $\theta = 0°C$, and for any given gas and species of ion $\Delta/k_0 = A_n/n_o e = 7.85 \times 10^{-5}$ erg/es; k_0 = mobility constant of the ion considered; n_o = Loschmidt's number; e = electronic charge. Sign of ion is indicated by subscript $_+$ or $_-$. Unit of $\Delta = 0.01$ cm²/sec; of $P = 1$ mm of Hg; of temperature (θ) = 1°C.

Dry gases

Gas	P	Δ_+	Δ_-	θ	Lit.
Air	1128	2.2	2.7		(127)
Air	772	3.17	4.29	19	(138)
Air		2.90*	4.48*		(47)
Air	760	3.2	4.2		(127)
Air	758	3.2	4.2		(127)
Air	550	4.20	5.42	18	(138)
Air	400	5.78	7.80	16	(138)
Air	300	7.86	10.3	13	(138)
Air	200	11.8	15.5	12	(138)
N_2	1302	1.7	2.6		(127)
N_2	1120	2.0	2.8		(127)
N_2	1000	2.3	3.14		(127)
N_2	760	2.9	4.1		(127)
N_2	760	2.95	4.14		(127)
O_2	760	3.0	4.1		(127)
CO_2	760	2.5	2.6		(127)

Effect of moisture (139)

Gas	Δ_+		Δ_-	
	Dry	Moist	Dry	Moist
Air	2.8	3.2	4.3	3.5
O_2	2.5	2.88	3.96	3.58
CO_2	2.3	2.45	2.6	2.55
H_2	12.3	12.8	19.0	14.2

* Estimated correct within 6 %.

Table 7.—Coefficient (α) of Recombination of Normal Ions: One Pressure and Room Temperature

$-\frac{dn}{dt} = \alpha n_+ n_-$; n_+, n_- = number of + ions and − ions, respectively, per cm³; n = either n_+ or n_-; t = time, in seconds. Unit of pressure (P) = 1 mm of mercury; of $\alpha = 10^{-6}$ cm³ per (ion sec).

Gas	P	α				
Air	760	1.63	1.50	1.72	1.89	1.61
O_2	760	1.61				
H_2	760	1.49				1.40
CO	757			0.87		
CO_2	760	1.67	1.62	1.67	2.33	1.66
CH_3I	28				0.56	
C_2H_5Cl	100				1.35	
C_2H_5Br	28				0.69	
$(C_2H_5)_2O$	95				1.51	
N_2O	749			1.35		
SO_2	680			1.31		
Lit		(137)	(60)	(132)	(106)	(91*)

* McClung used α-particles from radium.

Table 8.—Coefficient (α) of Recombination of Normal Ions: Variation with Pressure (P) (*cf.* Table 7)

For methods of measurement and discussion of observations, *see also* (29, 53, 61, 91, 105, 106, 120, 123, 135, 137). Unit of P = 1 mm of Hg; of $\alpha = 10^{-6}$ cm³ per (ion sec).

P	α	P	α	P	α
Air (60)		Air (53).—(*Cont'd*)		CO_2 (132).—(*Cont'd*)	
152	0.28	250	0.99	729	1.64
375	0.67	450	1.26	CO (132)	
760	1.50	760	1.57	247	0.22
1 550	1.7	(120)		409	0.44
2 320	1.5	280	1.77	556	0.62
3 800	1.0	420	1.85	690	0.76
(132)		540	2.05	757	0.87
197	0.44	745	2.13	SO_2 (132)	
307	0.73	CO_2 (60)		83.5	0.26
363	0.82	135	0.18	200	0.42
462	1.02	352	0.88	338	0.72
644	1.44	550	1.20	444	0.91
662	1.47	758	1.60	504	1.07
743	1.66	1 560	1.47	680	1.31
(53)		2 380	0.98	N_2O (132)	
10	0.48	(132)		200	0.33
20	0.55	175	0.49	294	0.53
35	0.60	265	0.67	430	0.81
50	0.63	373	0.92	596	1.13
100	0.74	498	1.19	749	1.33
150	0.84	614	1.44		

Table 9.—Coefficient (α) of Recombination of Normal Ions: Variation with Temperature (*cf.* Table 7)

Data for variation with temperature are very discordant. For relative values for CO_2 and H_2, *see* (30). Following values are for air at constant density (α_d) and at constant pressure (α_P); the latter are relative to $\alpha = 1.7 \times (10)^{-6}$ cm³ per (ion sec) at 289°K = 16°C. Unit of α_d and $\alpha_P = 10^{-6}$ cm³ per (ion sec); temperature = T, °K.

T	94	205	285	289	337	373	428	449	546	Lit.
α_d	2.55	1.92	1.18		0.78	0.59	0.47			(29)
α_P				1.7		0.85	0.68	0.61	0.30	(105)

Table 10.—Mobility (k) of Slow Ions

Moist air at pressure = 1 atmosphere; p = partial pressure of water vapor present. Sign of ion is indicated by subscript $_+$ or $_-$. (For classification of slow ions, *see* p. 110.) Unit of $k = 10^{-4}$ cm²/(volt sec); of $p = 1$ mm of Hg; temperature = t, °C.

p	k	p	k
Ions of Type I (107), t = 20°C			
0.67	7.99	11.80	3.67*
5.87	6.85	14.90	3.25
8.85	4.33*	15.51	3.17
10.24	3.90*	16.05	3.10
11.11	3.79*		

* A single measurement.

p	k_+	k_-	t
Ions of Type II (108)			
0.78	668		21.8
0.73	658		20.8
0.68		568	19.7
4.97		257	18.4
7.33	207		24.8
5.92		233	20.0
6.41		189	21.3
11.67		202	20.9

p	k_+	k_-	t
Ions of Type II.—(*Cont'd*)			
10.82		189	20.9
14.18	187		24.5
6.66		183	15.3
13.29	181		20.4
11.29	178		20.1
14.11	166		21.6
15.66	158		23.9
15.43	153		22.6
13.16	146		21.0
15.58	116		24.3
14.40	110		24.2
13.89	91		22.1
14.35		81	22.2
15.43		73.8	22.2
16.67		71.5	24.5

TABLE 10.—(*Continued*)
Ions of Type II.—(*Cont'd*)

p	k_+	k_-	t	p	k_+	k_-	t
14.87		64.1	23.4	16.88	28.6		19.5
14.06	63.6		22.8	17.09	24.6		19.7

Heterogeneous Slow Ions [8]

Source is hot Pt. Air is saturated with water vapor; k refers to the type of ion that is the most numerous. Unit of $k = 10^{-2}$ cm²/(volt sec); of age = 1 sec.

Age..	2	4	6	8	12	16	22	32	45	58	70
k....	6	4.2	2.9	2.6	2.3	2.0	1.6	1.2	0.9	0.75	0.65

TABLE 11.—MIGRATIONAL (v) AND THERMAL (u) VELOCITIES OF ELECTRONS IN GASES AT 15°C

If k = mobility of electrons in the gas considered, $v = kF$, where F = strength of the electric field; the velocity of agitation $u = 1.15c(10)^7$ cm/sec, where c^2 is determined from the lateral scattering of a beam of electrons in an electric field due to diffusion (*see* [139]); the mean free path (l) of the electrons is that defined [139] by $v = 0.815eFl/mu$; l_1 is the value of l when pressure (P) is 1 mm of Hg, and temperature = 15°C; in the units named below, $l_1 = 0.0797vcP/F$. For actual values of F and P, *see* original papers. Unit of F = 1 volt/cm; of P = 1 mm of Hg; of l_1 = 0.01 cm; of $v = 10^5$ cm/sec; of $k = 10^3$ cm²/(volt sec); c is dimensionless; $u = 1.15c(10)^7$ cm/sec.

A [141]; $10 < F < 50$; $2 < P < 150$

F/P	v	c^2	l_1
15.00	82.0	324	7.92
10.00	65.0	324	9.42
5.00	40.0	310	11.3
1.25	7.7	320	8.88
0.950	6.00	280	8.52
0.710	4.85	240	8.52
0.525	4.15	200	9.02
0.440	3.85	180	9.44
0.355	3.6	160	10.3
0.275	3.4	140	11.8
0.195	3.25	120	14.7
0.125	3.1	100	20.0

H_2 [140]; $4 < F < 35$; $0.6 < P < 40$

56	248	146	4.27
50	217	138	4.07
40	166	123	3.67
30	106	104	2.87
20	72	78	2.53
10	40.7	44	2.15
5	26.7	25.5	2.14
3	20.2	18.6	2.31
1.5	14.4	12	2.66
1	11.9	9	2.86
0.5	9.0	5.2	3.25
0.25	6.5	3.1	3.64

H_2 [78]; $10 < F < 100$; $100 < P < 760$

$k_0 = 432/[55.2 + F(760/P)^{3/4}]$,

$v = 760k_0F/P$

He [142]; $2 < F < 27$; $5 < P < 240$

5.0	30.2	172.0	6.4
4.0	23.5	152.0	5.85
3.0	17.5	137.0	5.5
2.5	15.0	124.0	5.4

He [142].—(*Continued*)

F/P	v	c^2	l_1
2.0	12.7	105.0	5.25
1.5	10.5	79.5	5.0
1.00	8.25	53.0	4.85
0.50	5.74	27.0	4.8
0.20	3.93	11.3	5.3
0.10	2.96	6.20	5.95
0.05	2.14	3.68	6.6
0.02	1.33	2.12	7.8
0.013	1.11	1.77	9.14

He [78]; $10 < F < 100$; $100 < P < 760$

$k_0^2 = 757/[1.565 + 760F/P]$,

$v = 760k_0F/P$

N_2 [140]; $4 < F < 34$; $0.3 < P < 20$

60	193	126	2.89
50	171	108	2.83
40	146	89	2.75
30	117	72.5	2.67
20	86	59.5	2.66
10	48.5	48.5	2.69
5	27	41.3	2.77
3	17.8	35.5	2.82
2	13.1	30.5	2.88
1	8.7	21.5	3.20
0.5	6.2	13	3.55
0.25	5.15	7.5	4.50

N_2 [78]; $10 < F < 100$; $100 < P < 760$

$k_0 = 363.7/[11.9 + 760F/P]$,

$v = 760k_0F/P$

N_2 [151]; $P = 760$; alternating potential of frequency $1000n$ per sec.

F	k	n
1.01	17.9	5.30
1.16	18.1	6.21

TABLE 11.—(*Continued*)

N_2 [151].—(*Continued*)

F	k	n
1.22	17.7	6.30
2.2	18.0	11.50
2.9	17.6	15.05
3.6	17.4	18.60
4.2	17.5	21.50
5.0	17.0	25.00
6.3	16.2	29.70
5.5	16.2	16.67
6.9	15.5	30.90
8.0	15.9	37.00
13.0	13.3	50.50
17.5	11.85	60.1
23.2	10.30	68.5
26.1	9.42	71.1
33.5	7.95	77.0
35.8	7.52	79.1
39.0	7.25	81.3
43.3	6.80	84.5
48.0	6.11	85.3
55.5	5.50	87.7

O_2 [140]; $4 < F < 35$; $1 < P < 10$

F/P	v	c^2	l
50	201	136	3.74
20	86	70	2.89
14	61	55.5	2.57
10	46	50	2.58
6	36	45	3.22
2	30	22.5	5.6

$A + H_2$ [141]; (?) $< F <$ (?); (?) $< P <$ (?)

96% A + 4% H_2

64.8	26.5	140	0.39
42.4	25.4	100	0.48
26.0	23.5	70	0.61
15.6	20.8	50	0.76
10.8	19.0	40	0.89
6.55	16.7	30	1.12
3.25	13.6	20	1.51
2.25	12.2	16	1.75
1.72	11.1	13	1.87
1.28	10.00	10	1.99
1.0	9.10	8	2.08
0.75	7.95	6	2.09
0.5	6.35	4	2.05

Air [140]; (?) $< F <$ (?); (?) $< P <$ (?)

F/P	v	c^2	l
100	270	160	2.72
50	173	102	2.78
20	90	57	2.71
10	52	46	2.82
5	30	38	2.96
2	17.5	22	3.28
1	12.5	11	3.30
0.5	9	5.7	3.37

For relations found with parallel plates, P = 40 to 90 mm, *see* [75].

NO [129]; $2 < F < 35$; $1 < P < 10$

13	84	37.0	1.42
10	74	21.7	0.88
8	66	16.7	0.73
5	51	13.3	0.84
4	45	12.2	0.97
3	38	11.0	1.10
2	30	9.3	1.21
1	22	7.0	1.37

N_2O [129]; $2 < F < 17$; $0.6 < P < 10$

13.33	48	13.9	
6.66	49	9.2	
3.33	46	5.0	
1.66	32	2.70	
0.83	16.2	1.81	
0.42	7.5	1.32	

CO [129]; $2 < F < 35$; $0.3 < P < 40$

50	152	86	2.24
40	114	68	1.87
30	80	52	1.53
20	57	42	1.47
10	38	34	1.76
5	28.5	22.7	2.16
3	26.0	16.0	2.76
2	23.0	11.0	3.04
1	18.0	5.5	3.36
0.5	13.0	4.80	4.52
0.25	9.0	3.20	5.14

CO [150]; $5 < F < 100$; $100 < P < 723$

$k = 1\,870/[P\sqrt{0.005 + (F/P)}]$

$v = Fk \times 10^{-2}$

TABLE 12.—NUMBER (N) OF MOLECULAR IMPACTS OF AN ELECTRON BEFORE ITS ATTACHMENT TO FORM A NORMAL NEGATIVE ION

N appears to be independent of pressure (observations from P = 20 mm to P = 760 mm), but increases with the initial velocity (v_i) of the electron (*see* end of table). Values tabulated refer to 15°C and are rather rough approximations. $N = A \times 10^n$ [5, 72, 77, 79, 88, 148].

Gas	A	n	Observer	Gas	A	n	Observer
A.....	∞		Franck	He.....	∞		Franck
Cl_2.....	<2.1	3	Wahlin	N_2.....	∞		Loeb
H_2.....	∞		Loeb	Ne.....	∞		Townsend

TABLE 12.—(*Continued*)

Gas	A	n	Observer	Gas	A	n	Observer
O_2	8.7	3	Loeb	C_2H_4	4.7	7	Wahlin
HCl*	<2	3	Loeb	C_2H_5Cl	3.7	5	Wahlin
H_2S*	2	4	Loeb	C_2H_6	2.5	6	Wahlin
SO_2*	<2	3	Loeb	$(C_2H_5)_2O$*	4	4	Loeb
NH_3	9.9	7	Wahlin	Air§	1.98	5	Loeb
N_2O	6.1	5	Loeb	Air	4.3	4	Loeb
CO	1.6	8	Wahlin	Air_{33}‖	3.0	5	Bailey
CO_2†	1.5	7	Loeb	Air_{45}‖	5.0	5	Bailey
CO_2‡	2.1	5	Loeb	Air_{60}‖	1.4	6	Bailey
C_2H_2	7.8	6	Wahlin				

* Values estimated relative to air, from pressure at which free electrons appear (79, 80, 88, 89). † Fresh CO_2. ‡ CO_2, 22 hr old. § Accurate absolute value; dry air, P between 20 and 760 mm (77). ‖ Subscript indicates value of v_i; unit = 10^6 cm/sec; *e.g.*, for air_{33}, $v_i = 33 \times 10^6$ cm/sec.

TABLE 13.—CONDENSATION OF VAPORS ON IONS AND NUCLEI

The degree of supersaturation (S) of a vapor subjected to adiabatic expansion is defined as the ratio of the vapor pressure after the expansion to the pressure of the saturated vapor at the temperature of the gas after its expansion.

When water vapor is supersaturated by adiabatic expansion, four stages of condensation are recognized: Condensation occurs on dust particles and on certain products of chemical action if $S < 4$; begins to occur on $-$ ions at $S = 4$ *ca.*, on $+$ ions at $S = 6$ *ca.*, and on uncharged water nuclei at $S > 6$. The nature of the gas in which the vapor is distributed has no effect upon the value of S required to initiate a given type of condensation. $E \equiv V_2/V_1$ = adiabatic expansion necessary to produce condensation, $V_1[V_2]$ = volume of moist gas before [after] expansion. E_0, E_-, E_+ = value of E corresponding to condensation on uncharged water nuclei, on $-$ ions, on $+$ ions; S_0, S_-, and S_+ are the values of S corresponding to E_0, E_-, and E_+. When the sign of the ion is not known the value of E is placed between the columns for E_- E_+.

Formula	Vapor	E_0	E_-	E_+	S_+	Lit.
H_2O	Water*	1.38	1.25	1.31	5.8	(157)
H_2O	Water	1.42	1.29			(28)
H_2O	Water	1.366	1.265	1.314		(111)
H_2O	Water†	1.31	1.270	1.32		(3)
H_2O	Water		1.251			(58)
CCl_4	Carbon tetrachloride		1.89			(28)
CS_2	Carbon disulfide	1.08	1.05			(28)
CS_2	Carbon disulfide		1.02			(111)
$CHCl_3$	Chloroform		1.598	1.528	3.0	(111)
C_2H_5I	Ethyl iodide		1.530	1.484		(111)
C_6H_5Cl	Chlorobenzene	1.60	1.48			(28)
C_6H_6	Benzene	1.78	1.53			(28)
C_6H_6	Benzene	1.74	1.50			(3)
C_6H_6	Benzene‡		1.642			(111)
C_3H_6O	Acetone		2.009			(111)
CH_4O	Methyl alcohol	1.42		1.32		(28)
CH_4O	Methyl alcohol	1.378	1.306	1.251	2.3	(111)
C_2H_6O	Ethyl alcohol	1.25		1.20		(28)
C_2H_6O	Ethyl alcohol	1.254	1.200	1.175	2.3	(111)
C_2H_6O	Ethyl alcohol	1.190	1.158	1.180		(3)
C_3H_8O	*n*-Propyl alcohol	1.237	1.201	1.178	3.1	(111)
$C_4H_{10}O$	Isobutyl alcohol	1.260	1.215	1.198	3.6	(111)
$C_5H_{12}O$	Isoamyl alcohol	1.293	1.233	1.218	5.5	(111)
$C_5H_{12}O$	Isoamyl alcohol			1.182	4.1	(58)
$C_5H_{12}O$	*n*-Amyl alcohol	1.354	1.307	1.271		(111)
$C_7H_{16}O$	Heptyl alcohol	1.362	1.306	1.269		(111)
CH_2O_2	Formic acid			1.782	25.1	(58)
$C_2H_4O_2$	Acetic acid			1.441	9.3	(58)
$C_3H_6O_2$	Propionic acid			1.343	9.4	(58)
$C_4H_8O_2$	*n*-Butyric acid			1.380	15.0	(58)
$C_4H_8O_2$	Isobutyric acid			1.360	13.3	(58)
$C_5H_{10}O_2$	Isovaleric acid			1.220	6.0	(58)
$C_4H_8O_2$	Ethyl acetate			1.486	8.9	(58)

TABLE 13.—(*Continued*)

Formula	Vapor	E_0	E_-	E_+	S_+	Lit.
$C_5H_{10}O_2$	Methyl *n*-butyrate			1.334	5.3	(58)
$C_5H_{10}O_2$	Methyl isobutyrate			1.347	5.2	(58)
$C_5H_{10}O_2$	Ethyl propionate			1.414	7.8	(58)
$C_5H_{10}O_2$	*n*-Propyl acetate			1.310	5.0	(58)

* For H_2O, $S_0 = 7.9$, $S_- = 4.15$ (157). † For H_2O, $S_0 = 6$ (3). ‡ For C_6H_6, ions of unknown sign, $S = 4.3$ (111).

EFFECTIVE SECTIONAL AREA OF MOLECULES* (1, 2, 11, 12, 13, 14, 15, 16, 17, 48, 54, 64, 65, 66, 93, 95, 113, 114, 115, 116, 117, 119, 121, 130, 161, 162)

When a beam of electrons passes through a gas, the number (n_x) of electrons remaining in the beam after it has gone a distance x is given by the equation, $n_x = n_0 e^{-qpx}$, where p is the pressure of the gas. If the cross-sectional area of an electron is negligible as compared with that of a molecule, and if the velocities of the molecules are negligible, as compared with that of the electron, then qp will be the sum of the cross-sectional areas of all the molecules in a unit volume. By definition the mean free path of an electron, L_e is defined as $1/qp$. If the effective cross-sectional area of a molecule for an encounter with another molecule were the same as that for an encounter with an electron, then we would have $L_e = 4\sqrt{2}L$, where L is the mean free path of the molecule in the gas.† It is found that qp varies with the velocity of the electrons and that $1/qp$ or L_e is not equal to $4\sqrt{2}L$. (It should be noticed that L_e is not the same quantity as that denoted by l in Table 11.) The absorbing cross-section of all the molecules in a unit volume of gas at the temperature t and at unit pressure is q. The effective radius, r, of the absorbing cross-section of a single molecule is given by the equation $\pi r^2 = q/N_t$, where N_t is the number of molecules per unit volume at the temperature t and at unit pressure. For electrons with high velocities (β-rays), q has such a value that r is of the same order of magnitude as the radius of the nucleus, as deduced from the scattering of α-particles. In actual measurements, the beam of electrons must have a finite width, and, consequently, those electrons that have been deviated from their initial path by less than a certain amount, determined by the apparatus used, are not eliminated from the beam. This source of error makes the computed value of q too small, and causes the results of different observers to differ slightly. In most cases, the deviation of an observer's separate determinations from the mean curve representing all his values is less than 10%.

Typical data are shown in Figs. 10 to 14:

Molecule	A	Cd	CH_4	CO	CO_2	H_2	He	Hg
Figures	10	14	11	12	13	11	11	14

Molecule	Kr	N_2	NO	N_2O	Ne	O_2	Xe	Zn
Figures	10	12	13	13	10	13	10	14

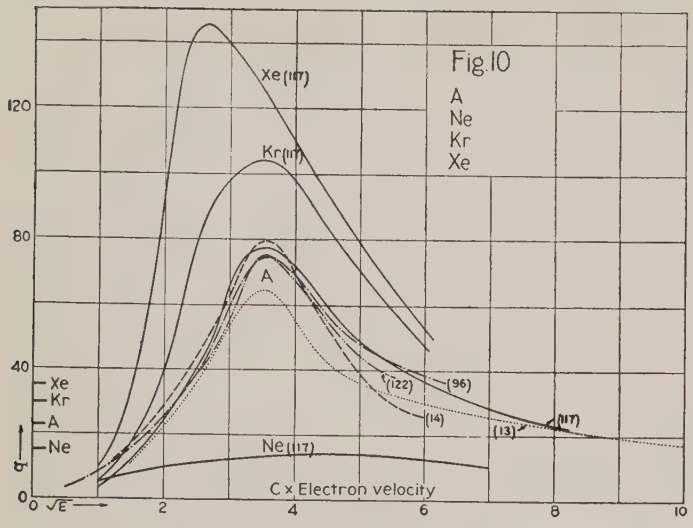
*In collaboration with R. B. Brode.

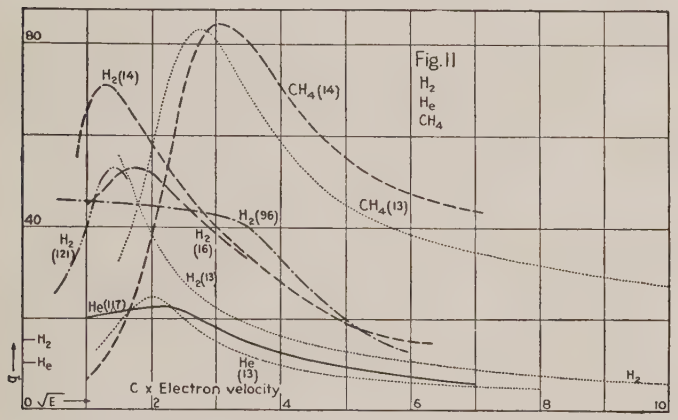
† In figures, short line followed by symbol for gas on axis of ordinates indicates gas kinetic value, $4\sqrt{2}L$.

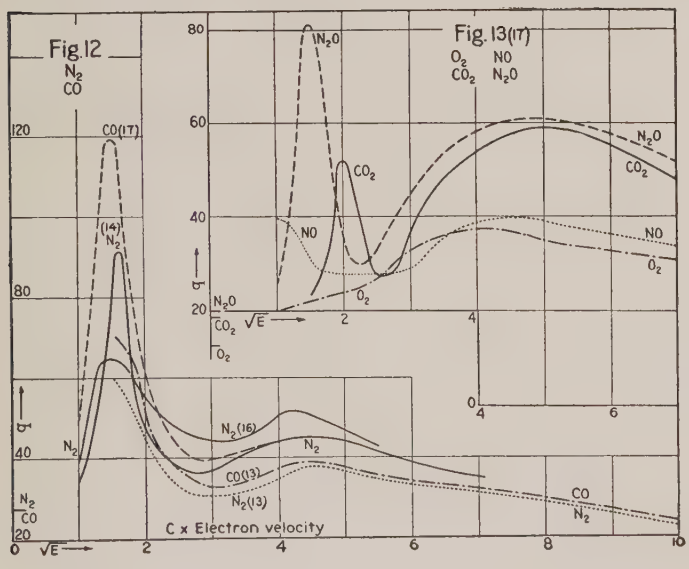
LITERATURE

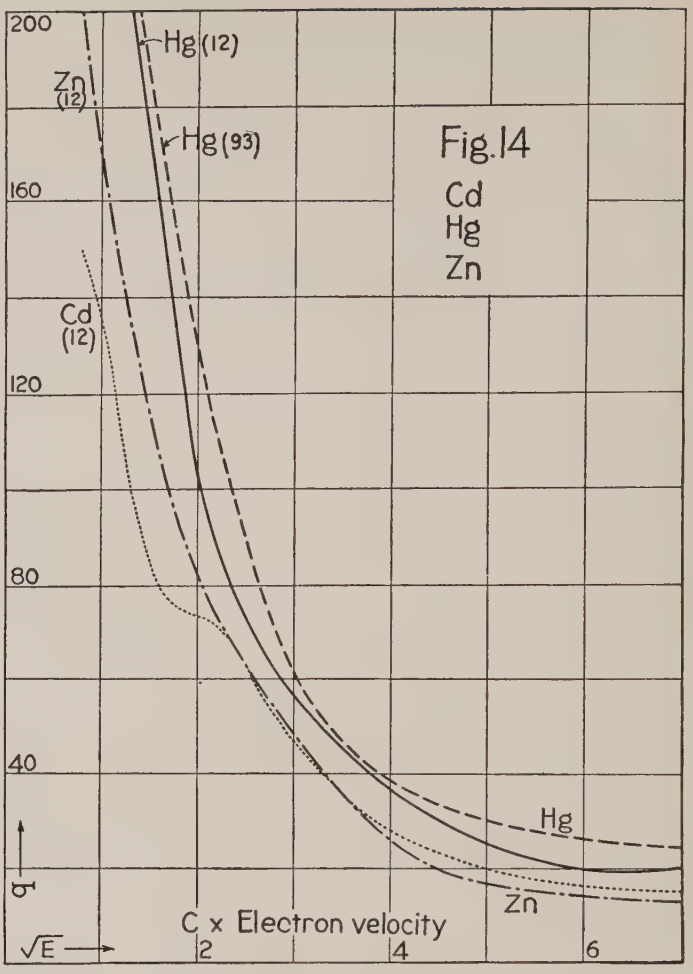
(For a key to the periodicals see end of volume)

(1) Åkesson, *171*, **5**: No. 21; 14. (2) Åkesson, *215*, **12 II**: 11; 16. (3) Andrén *8*, **52**: 1; 17. (4) Bailey, *3*, **46**: 213; 23. (5) Bailey, *3*, **50**: 825; 25. (6) Becker, *8*, **17**: 381; 05. (7) Bělař, *75*, **130 IIa**: 373; 21. (8) Blackwood, *2*, **16**: 85; 20. (9) Blackwood, *2*, **20**: 499; 22.
(10) Blanc, *51*, **7**: 825; 08. (11) Brode, *2*, **23**: 664; 24. (12) Brode, *5*, **109**: 397; 25. (13) Brode, *2*, **25**: 636; 25. (14) Brüche, *8*, **81**: 537; 26. (15) Brüche, *8*, **82**: 25; 27. (16) Brüche, *8*, **82**: 912; 27. (17) Brüche, *8*, **83**: 1065; 27. (18) Busse, *8*, **76**: 493; 25. (19) Busse, *8*, **81**: 262; 26.
(20) Busse, *8*, **81**: 587; 26. (21) Busse, *8*, **82**: 697; 27. (22) Busse, *8*, **82**: 873; 27. (23) Busse, *8*, **83**: 80; 27. (24) Chattock, *3*, **48**: 401; 99. (25) Compton, *2*, **22**: 333; 23. (26) Compton, *2*, **22**: 432; 23. (27) Dempster, *2*, **34**: 53; 12. (28) Donnan, *3*, **3**: 305; 02. (29) Erikson, *3*, **18**: 328; 09.
(30) Erikson, *3*, **23**: 747; 12. (31) Erikson, *2*, **3**: 151; 14. (32) Erikson, *2*, **6**: 345; 15. (33) Erikson, *2*, **20**: 117; 22. (34) Erikson, *2*, **21**: 720; 23. (35)









FIGS. 10 to 14.—Effective sectional areas of molecules.

(For general discussion and index, *see* p. 117.) These curves represent typical values deduced from electronic data. q = sum of the effective absorbing cross-sectional areas of all the molecules contained in a unit volume of the gas at 0°C and a pressure of 1 mm Hg; unit of q = 1 cm² per cm³. The velocity of the electrons is indicated by numbers equal to the square root of the voltage through which the electron has been accelerated. The equation connecting velocity (v) and volts (V), for slow electrons only, is $\frac{1}{2}\,mv^2 = eV$, or $v = 0.595 \times 10^8\sqrt{V}$ cm/sec, where **m** is the mass of an electron and **e** its charge.

For some gases, the corresponding sum of the cross-sectional areas involved in the molecular encounters considered in the kinetic theory of gases is indicated by a short dash at the axis of ordinates. Literature references are enclosed in ( ).

Erikson, *2*, **24**: 502; 24. (36) Erikson, *2*, **24**: 622; 24. (37) Erikson, *2*, **26**: 465; 25. (38) Erikson, *2*, **26**: 625; 25. (39) Erikson, *2*, **26**: 629; 25. (40) Erikson, *2*, **28**: 372; 26. (41) Erikson, *2*, **30**: 339; 27. (42) Franck, *88*, **11**: 397; 09. (43) Franck, *88*, **12**: 291; 10. (44) Franck, *88*, **12**: 613; 10. (45) Franck, *200*, **9**: 235; 12. (46) Franck and Pohl, *88*, **9**: 69; 07. (47) Franck and Westphal, *88*, **11**: 146; 09. (48) Glockler, *197*, **10**: 155; 24. (49) Grindley and Tyndall, *3*, **48**: 711; 24.

(50) Haines, *3*, **30**: 503; 15. (51) Harries, *96*, **42**: 26; 27. (52) Haselfoot, *5*, **87**: 350; 12. (53) Hendren, *2*, **21**: 314; [illegible] (54) Hertz, *64P*, **25**: 90; 23.

(55) Kleeman, *2*, **19**: 541; 22. (56) Kovarik, *2*, **30**: 415; 10. (57) Kovarik, *5*, **86**: 154; 12. (58) Laby, *62*, **208**: 445; 08. (59) Langevin, *Thesis*, Paris, 1902.

(60) Langevin, *6*, **28**: 433; 03. (61) Langevin, *6*, **5**: 245; 05. (62) Langevin, *34*, **140**: 232; 05. (63) Langevin and Moulin, *34*, **140**: 305; 05. (64) Lenard, *8*, **12**: 449; 03. (65) Lenard, *8*, **12**: 714; 03. (66) Lenard, *Quantitatives über Kathodenstrahlen aller Geschwindigkeiten*. Heidelberg, Winter, 1925. (67) Loeb, *143*, **184**: 775; 17. (68) Loeb, *197*, **6**: 435; 20. (69) Loeb, *2*, **17**: 89; 21.

(70) Loeb, *2*, **19**: 24; 22. (71) Loeb, *2*, **20**: 397; 22. (72) Loeb, *3*, **43**: 229; 22. (73) Loeb, *143*, **196**: 537; 23. (74) Loeb, *143*, **196**: 771; 23. (75) Loeb, *197*, **9**: 335; 23. (76) Loeb, *3*, **48**: 446; 24. (77) Loeb, *143*, **197**: 45; 24. (78) Loeb, *2*, **23**: 157; 24. (79) Loeb, *197*, **11**: 428; 25.

(80) Loeb, *197*, **12**: 35; 26. (81) Loeb, *197*, **12**: 617, 677; 26. (82) Loeb, *143*, **201**: 279; 26. (83) Loeb, *197*, **13**: 703; 27. (84) Loeb, *Kinetic theory of gases*. New York, McGraw-Hill, 1927. (85) Loeb and Ashley, *197*, **10**: 351; 24. (86) Loeb and Cravath, *2*, **27**: 811; 26. (87) Loeb and Du Sault, *197*, **13**: 510; 27. (88) Loeb and Du Sault, *197*, **14**: 192; 28. (89) Loeb and Du Sault, *197*, **14**: 384; 28.

(90) McClelland and Nolan, *539*, **33**: 24; 16. (91) McClung, *3*, **3**: 283; 02. (92) McLennan and Keys, *3*, **30**: 484; 15. (93) Maxwell, *197*, **12**: 509; 26. (94) Mayer, *8*, **62**: 358; 20. (95) Mayer, *8*, **64**: 451; 21. (96) Mayer, *63*, **28**: 637, 1026; 27. (97) Millikan, *The Electron*. Chicago, Univ. Chicago Press, 1924. (98) Nolan, *539*, **33**: 9; 16. (99) Nolan, *5*, **94**: 112; 18.

(100) Nolan, *2*, **24**: 16; 24. (101) Nolan, *3*, **1**: 417; 26. (102) Nolan, *8*, **82**:

273; 27. (103) Nolan and de Sachy, *539*, **37**: 71; 27. (104) Phillips, *5*, **78**: 167; 06. (105) Phillips, *5*, **83**: 246; 10. (106) Plimpton, *3*, **25**: 65; 13. (107) Pollock, *3*, **29**: 514; 15. (108) Pollock, *3*, **29**: 636; 15. (109) Przibram, *75*, **117 IIa**: 665; 08.
(110) Przibram, *75*, **118 IIa**: 331; 09. (111) Przibram, *200*, **8**: 285; 11. (112) Przibram, *in B95*, **XXII**. (113) Ramsauer, *8*, **64**: 513; 21. (114) Ramsauer, *8*, **66**: 546; 22. (115) Ramsauer, *8*, **72**: 345; 23. (116) Ramsauer, *200*, **19**: 345; 23. (117) Ramsauer, *8*, **83**: 1129; 27. (118) Ratner, *3*, **32**: 441; 16. (119) Robinson, *8*, **31**: 769; 10.
(120) Rümelin, *8*, **43**: 821; 14. (121) Rusch, *63*, **26**: 748; 25. (122) Rusch, *8*, **80**: 707; 26. (123) Rutherford, *3*, **44**: 422; 97. (124) Rutherford, *201*, **9**: 401; 98. (125) Rutherford, *3*, **5**: 95; 03. (126) Rutherford, *Radioactive substances and their radiations*. Cambridge, Cambridge Univ. Press, 1913. (127) Salles, *16*, **2**: 273; 14. (128) Schilling, *8*, **83**: 23; 27. (129) Skinker and White, *3*, **46**: 630; 23.
(130) Sponer, *96*, **18**: 249; 23. (131) Stücklin, *in B95*, **XIV**. (132) Thirkill, *5*, **88**: 477; 13. (133) Thomson, *Conduction of electricity through gases*. Cambridge, Cambridge Univ. Press, 1906. (134) Thomson, *3*, **30**: 321; 15. (135) Thomson, *3*, **47**: 337; 24. (136) Todd, *3*, **25**: 163; 13. (137) Townsend, *62*, **193**: 129; 00. (138) Townsend, *62*, **195**: 259; 01. (139) Townsend, *Electricity in gases*. Oxford, Clarendon Press, 1915.
(140) Townsend and Bailey, *3*, **42**: 873; 21. (141) Townsend and Bailey, *3*, **44**: 1033; 22. (142) Townsend and Bailey, *3*, **46**: 657; 23. (143) Townsend and Tizard, *5*, **87**: 357; 12. (144) Townsend and Tizard, *5*, **88**: 336; 13. (145) Tyndall and Grindley, *3*, **47**: 689; 24. (146) Tyndall and Grindley, *5*, **110**: 341; 26. (147) Tyndall and Phillips, *5*, **111**: 577; 26. (148) Wahlin, *2*, **19**: 173; 22. (149) Wahlin, *2*, **20**: 267; 22.
(150) Wahlin, *2*, **21**: 517; 23. (151) Wahlin, *2*, **23**: 169; 24. (152) Wahlin, *197*, **10**: 475; 24. (153) Wellisch, *5*, **82**: 500; 09. (154) Wellisch, *62*, **209**: 249; 09. (155) Wellisch, *3*, **34**: 33; 17. (156) Wellisch, *12*, **44**: 1; 17. (157) Wilson, *62*, **189**: 265; 97. (158) Yen, *197*, **4**: 91; 18. (159) Yen, *197*, **4**: 106; 18.
(160) Zeleny, *62*, **195**: 193; 01. (161) Zwicky, *63*, **24**: 171; 23. (162) Zwicky, *197*, **12**: 461; 26.

IONIZATION OF GASES

O. Stuhlman, Jr.

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This section includes ionization by impact of electrons, of positively charged residues, and of α-particles, by electromagnetic radiation and by chemical action. Data for the conductivity of flames, for ionization potentials, and for photoelectric thresholds are given elsewhere; *consult* p. 156, 69 and 67, respectively.

The following symbols will be used:

c	velocity of light in vacuum.
C	Coefficient of ionization; $n = Cp/T$.
C_r	C_1/C_2 for the same ionizing radiation (corpuscular or electromagnetic) = coefficient of relative molecular ionization of gas (1) with reference to gas (2).
E_i	Energy expended in producing one pair of ions.
E_1	Kinetic energy possessed by the charged particle at the beginning of its ionizing career.
e	Electronic charge.
^-i	α/p; $^+i = \beta/p$.
^-I	$\int_0^\infty {}^-i\,dx$; $^+I = \int_0^\infty {}^+i\,dx$.
$^-Np[^+Np]$	Number of encounters of an electron [a + ion] per cm of its path; the superior $^-[^+]$ may be omitted where convenient.
n	Number of ions produced per sec in 1 cm³ of a thin layer of gas at pressure p and absolute temperature T.
p	Pressure of the gas being ionized.
p_m	Pressure at which α is a maximum for a given X.
V	Potential difference required to confer the energy E upon a charge = e; $eV_1 = E_1$, $eV_i = E_i$, etc.
v	Velocity of the ionizing particle.
X	Intensity of the applied electric field.
$\alpha[\beta]$	Number of pairs of ions produced per cm of path by each electron [each + ion].
λ	Wave-length of the exciting radiation.

If the density of the gas remains constant, α, β and the number of ions produced per sec by a given electromagnetic radiation are all independent of the temperature (**10, 11, 14, 32, 33, 44**); tested (**10**) from −180 to +1600°C. If the velocity of the particles arises solely from X, then, for a given temperature and gas, α/p and β/p depend solely upon X/p (**63, 65, 66, 67, 69**). If X is so great that the effects of thermal agitation may be neglected, $\alpha = N_p e^{-N_p V_i/X}$ (**63**); hence $(\alpha_{max.})_{p\ const.} = Np$ and $(\alpha_{max.})_{X\ const.}$ occurs when $p(=p_m) = X/NV_i$ or $X/p_m = NV_i$; the value of N is determined from that of $(\alpha_{max.})_p$.

For expressions for the total current resulting from ionization by both electrons and positive residues, *see* (**3, 63**); for ionization of mixed gases, *see* (**3, 26**); for theory, *see* Bohr (**5, 6**) and Fowler (**19, 20**).

TABLE 1.—IONIZATION OF AIR BY ELECTRONS: VARIATION WITH VELOCITY (**4, 15, 16, 27, 71**)

$$V_1 = 5.082 \times 10^5 \left\{ \frac{1}{\sqrt{1-(v/c)^2}} - 1 \right\} \text{ volt.}$$

For $V_1 < 4000$ volt, v/c has been computed from observed value of V_1 by means of the approximate relation $v/c = 0.001983\sqrt{V_1}$, V_1 being expressed in volts; the corresponding expression for E_1 is $E_1 = 1.592 V_1 \times 10^{-12}$. Unit of α = 1 per cm; of p = 1 mm of Hg; of V_1 = 1 volt; $V_1 = A \times 10^n$.

A	n	$100v/c$	α/p	A	n	$100v/c$	α/p
		100	0.054	4.63	4	40	0.32
1.12	6	95	0.063	2.45	4	30	0.42
6.57	5	90	0.073	1.53	4	24	0.43*
3.39	5	80	0.092	1.05	4	20	1.04
2.03	5	70	0.125	9.42	3	19	1.14
1.27	5	60	0.173	8.43	3	18	1.25
7.86	4	50	0.242	7.50	3	17	1.38
6.63	3	16	1.50	7.00	2	5.246	6.19
5.82	3	15	1.68	6.00	2	4.857	5.43
4.77	3	13.6	2.01	4.94	2	4.407	6.43
2.225	3	9.353	3.46	3.97	2	3.951	7.84
1.808	3	8.432	4.98	3.72	2	3.825	9.18
1.500	3	7.680	6.96	3.47	2	3.694	9.36
1.400	3	7.420	7.85	2.95	2	3.406	9.12
1.200	3	6.869	10.32	2.47	2	3.116	13.8
1.105	3	6.601	12.04	1.98	2	2.790	14.6
1.050	3	6.425	12.85	1.56	2	2.477	23.6
9.92	2	6.246	13.82	1.22	2	2.190	37.8
9.85	2	6.223	13.91	8.4	1	1.82	51.4
9.72	2	6.183	13.69	4.7	1	1.36	95.0
9.52	2	6.118	13.50	4.1	1	1.27	111.2
9.05	2	5.965	12.36	3.5	1	1.17	108.2
8.90	2	5.916	10.14	2.8	1	1.05	82.7
8.00	2	5.609	6.72	1.8	1	0.841	51.2

* This value (**15**) seems to be much too small; it is the only value available between $v/c = 0.20$ and $v/c = 0.30$.

TABLE 2.—IONIZATION OF GASES BY ELECTRONS: VARIATION WITH VELOCITY (**34**)

For air, $v > 0.025c$, *see* Table 1. (v is computed from Einstein's formula, $m_0c^2\left(\frac{1}{\sqrt{1-(v/c)^2}} - 1\right) = V_1 e$.) Unit of V_1 = 1 volt; of α = 1 per cm; of p = 1 mm of Hg. Error ≤ 4%.

Gas		A	H_2	He	N_2	Ne	CH_4	CO*
V_1	$100v/c$	α/p						
300	3.44	4.14	1.264	0.648	4.460	1.502	4.36	4.296
280	3.33	4.54	1.362	0.699	4.775	1.557	4.72	
260	3.20	4.83	1.463	0.744	5.100	1.608	5.05	5.16†
240	3.09	5.31	1.568	0.782	5.420	1.666	5.41	
220	2.96	5.68	1.678	0.815	5.650	1.710	5.74	
200	2.80	6.03‡	1.785	0.844	6.080	1.754	6.20	6.052
180	2.67	6.36	1.902	0.867	6.425	1.800	6.43	
160	2.52	6.67	2.018	0.880	6.780	1.828	6.78	
140	2.36	6.95	2.137	0.881	7.125	1.820	7.14	
120	2.18	7.21	2.260	0.870	7.450	1.768	7.47	
100	1.99	7.45	2.376	0.846	7.640	1.651	7.82	7.595
80	1.78	7.65	2.487	0.804	7.470	1.450	8.06	
60	1.54	7.48	2.518	0.730	6.880	1.130	7.80	7.48†
40	1.25	6.74	2.280	0.500	5.580	0.630	6.79	
35	1.17	6.36	2.153	0.380	4.96	0.480	6.28	
30	1.08	5.56	1.947	0.229	4.09	0.320	5.55	
29	1.06	5.35	1.882	0.192	3.89	0.287	5.37	
28	1.04	5.13	1.825	0.155	3.68	0.255	5.20	
27	1.02	4.88	1.755	0.120	3.47	0.220	5.00	
26	1.00	4.61	1.670	0.082	3.24	0.180	4.80	
25	0.98	4.31	1.600		3.02	0.140	4.55	
24	0.96	4.00	1.500		2.80	0.095	4.30	
23	0.94	3.67	1.383		2.54	0.044	4.02	
22	0.92	3.30	1.260		2.28		3.72	
21	0.90	2.90	1.130		2.00		3.40	
20	0.88	2.45	0.980		1.72		3.05	
19	0.85	1.90	0.800		1.42		2.67	
18	0.83	1.29	0.595		0.80		2.26	
17	0.81	0.45	0.350				1.80	
16	0.79						1.28	
15	0.76						0.75	
14	0.73						0.10	

* Jesse (**35**). † Corresponds to V_1 midway between bracketed lines. ‡ Jesse (**35**) found 6.44.

TABLE 3.—RELATIVE MOLECULAR IONIZATION OF GASES BY β-RAYS FROM VARIOUS SUBSTANCES

$n_r \equiv n/n_a = C_r p T_a/p_a T$; n_a, p_a, T_a refer to air; p_a = 760 mm Hg; values of C_r

Gas	U-X (37, 38)	Ra (60)	Ac (37, 38)
Air	1.00	1.00	1.00
H_2	0.165*	0.157	0.159
O_2†	1.17	1.21	
SO_2	2.25	2.31	
N_2O†	1.55		
NH_3†	0.89		
CO_2†	1.60*	1.57	
CCl_4	6.28	5.83	
CS_2	3.62		
C_2N_2		1.86	
$CHCl_3$	4.94	4.89	
CH_3Br	3.73		
CH_3I	5.11	5.18	5.34
CH_4O	1.69		
C_2H_4O‡	2.12		
C_2H_5Br	4.41		4.43
C_2H_5Cl	3.24		3.33
C_2H_5I	5.90		
$C_4H_{10}O$§	4.39		4.28
C_5H_{12}‖	4.55		
C_6H_6¶	3.95		

* Bloch (4) finds: H_2, 0.13; CO_2, 1.59; illuminating gas (40 % H_2), 0.63.
† Commercial purity.
‡ Acetaldehyde. ‖ Pentane.
§ Ethyl ether. ¶ Benzene.

TABLE 4.—TOTAL NUMBER (I) OF PAIRS OF IONS PRODUCED BY AN ELECTRON IN FIELD OF ZERO INTENSITY

$I = \int_0^\infty i dx$, where $i \equiv \alpha/p$. If $0.6 < 100v/c < 2.8$, $I = c_1 (V - c_2)$; c_2 is not V_1, *cf.* Table 7. Unit of α = 1 per cm; of p = 1 mm of Hg; of V and c_2 = 1 volt; of I = 1000; of c_1 = 1 per volt.

Air: various β-rays				Slow electrons (36)		
Rays	α/p	I	Lit.	Gas	c_1	c_2
Ac-C″	0.174	10	(24)	H_2	0.0258	11
Th-C″	0.174	17	(24)	He	0.0244	20
Ra-B	0.171	3.7	(24)	N_2	0.0276	12
Ra-C	0.138	7.7	(24)	O_2	0.0275	11
		12	(18)			
Ra-E	0.088	3.3	(24)			
U-X	0.099	11.3	(24)			

TABLE 5.—IONIZATION OF GASES BY ACCELERATED ELECTRONS: VARIATION WITH INTENSITY (X) OF FIELD

For ionization and conductivity of mixed gases, *see* (3). For certain gases $\frac{\alpha}{p} = a\left(\frac{X}{p} - \frac{X_i}{p}\right)^b$, where X_i is weakest field in which ionization occurs (3); $X_i/p = NV_i$. Unit of X = 1 volt/cm; of p = 1 mm of Hg; of α = 1 per cm.

X/p	α/p				
	A	H_2*	H_2	He	He
600	9.2				
500	8.5				
400	7.5		3.7		
300	6.2		3.3		
200	4.4		2.62	2.37	
100	2.0		1.36	1.98	
70		0.62	0.76	1.65	
60		0.43	0.59	1.50	1.35

TABLE 5.—(*Continued*)

X/p	α/p				
	A	H_2*	H_2	He	He
50	0.58	0.27	0.36	1.31	1.20
40		0.14	0.21	1.10	1.00
30		0.04	0.08	0.86	0.77
25		0.015			
22.5		0.006			
20	0.05			0.57	0.40
15				0.42	
10				0.28	0.12
5				0.12	
Lit.	(25, 63)	(3)	(63)	(26)	(63)

X/p	α/p				
	N_2	H_2O	HCl	CO_2†	Air‡
1500			17.5		
1200				13.7	
1000		9.7	15.4	12.6	10.5
900		9.4			
800		9.0	14.0	11.0	9.3
700		8.5	13.0	10.2	8.7
600	7.0	7.95	11.9	9.1	7.9
500	6.2	7.2	10.5	7.8	7.0
400	5.2	6.35	8.9	6.4	5.82
300	3.95	5.2	6.8	4.8	4.4
200	2.3	3.6	4.1	2.8	2.6
100	4.2	1.31	1.21	0.82	0.72
70				0.27	0.17
60				0.17	0.078
50				0.079	0.029
40				0.020	
Lit.	(63)	(63)	(63)	(3, 63)	(3, 63, 64, 68)

* a = 266.7 × 10^{-6}, b = 1.615, X_i/p = 200; if 200 ≤ X/p ≤ 685 (3).
† a = 402.9 × 10^{-6}, b = 1.515, X_i/p = 356; if 356 ≤ X/p ≤ 755 (3).
‡ a = 159.4 × 10^{-6}, b = 1.615, X_i/p = 400; if 400 ≤ X/p ≤ 725 (3).

TABLE 6.—IONIZATION OF He BY ACCELERATED ELECTRONS: VARIATION WITH PRESSURE, FIELD CONSTANT

α is a maximum when $p_m = X/16$; compare with Table 7 where value for NV_i indicates a pressure less than half as great. Unit of X = 1 volt/cm; of p = 1 mm of Hg; of α = 1 per cm.

X = 120 (69)				X = 50 (66)			
α	p	α/p	X/p	α	p	α/p	X/p
3.05	19	0.160	6.3	1.37	10.5	0.130	4.75
3.46	10	0.346	12.0	1.22	10.0	0.122	5
3.57	6	0.595	20.0	1.56	3.13	0.498	16
3.37	4	0.842	30.0				

TABLE 7.—ENERGY (E_i) EXPENDED BY ELECTRONS IN IONIZING A MOLECULE: VARIOUS GASES

$E_i = eV_i$; Np = number of collisions per unit length of path of electron = maximum value of α for given p; $NV_i = X/p_m$, where p_m is the pressure at which α is a maximum for a given X. Unit of V_i = 1 volt; of Np = 1 per cm; of p = 1 mm of Hg.

Gas	V_i	N	NV_i	Lit.
Air	25	14.6	365	(63)
	27.1	12.6	341	(51)
	10.21*			(3)
A	17.3	13.6	235	(63)
H_2	26.0	5.0	130	(63)
	27.8	5.5	153	(51)
	9.66*			(3)
He	12.3	2.8	34.4†	(63)

TABLE 7.—(*Continued*)

Gas	V_i	N	NV_i	Lit.
He.—(*Continued*)	14.5	2.4	34.8†	(63)
N_2	27.6	12.4	342	(63)
	27.9	12.4	346	(51)
O_2	23.9	11.2	268	(51)
H_2O	22.4	12.9	289	(63)
HCl	16.5	22.2	366	(63)
CO_2	23.3	20.0	466	(63)
	23.5	16.2	381	(51)
	6.21*			(3)

* Observations at pressures >1 cm Hg.
† This exceeds twice the value of X/p_m given in Table 6.

TABLE 8.—IONIZATION OF AIR BY α-PARTICLES: VARIATION WITH VELOCITY

No appreciable ionization is produced by an α-particle unless $v > 0.025\mathbf{c}$ (53, 55). If, at a distance x from its source, an α-particle of range R, in the gas considered, produces βdx pairs of ions in a length of path $= dx$, then, quite roughly, $\beta = a/(R-x)^{1/3}$ and $v/\mathbf{c} = b(R-x)^{1/3}$ (22); for air, $a = 4.50 \times 10^4$ cm$^{-2/3}$ (23), $b = 0.0342$ cm$^{-1/3}$ (Vol. I, p. 362). For values of R and v_1 (initial velocity), *see* Vol. I, p. 362, 363. For α-particles from Ra-C′ in air at 12°C and 1 atm., β varies as follows (21):

x	1	2	3	4	5	6	6.5±	7± cm
$\beta/1000$	22.5	23	24	28	36	55	76	40 cm^{-1}

The total number of ions produced is $I = \int_0^R \beta dx = KR^{2/3}$, where $K = 1.50a$; for air, $K = 6.76 \times 10^4$ cm$^{-2/3}$ (22). Unit of $I = 1000$. Gas is air.

Source	$100v_1/\mathbf{c}$	I	Source	$100v_1/\mathbf{c}$	I
U_I	4.56	133	Rd-Ac	5.59	187
Th	4.69	137	Ra-A	5.65	187
U_{II}	4.79	143	Th-C	5.72	189
Io	4.85	146	Tn	5.74	195
Ra	5.00	152	Ac-C	5.89	205
Pa	5.10	160	Th-A	6.00	209
Ra-F*	5.23	167	An	6.00	211
Rd-Th	5.27	169	Ac-A	6.27	228
Rn	5.40	171	Ra-C′	6.41	237
Th-X	5.46	177	Th-C′	6.88	274
Ac-X	5.50	178			

* $I = 158$ (2).

TABLE 9.—RELATIVE MOLECULAR AND TOTAL (I_r) IONIZATION OF GASES BY α-PARTICLES FROM RADIUM AND POLONIUM

$n_r \equiv n/n_a = C_r p T_a/p_a T$; n_a, p_a, T_a refer to air. $v_1 = 0.0500\mathbf{c}$; for ionization of air, *see* Table 8

Gas	Ra		Po	Gas	Ra		Po
	C_r*	I_r*	I_r†		C_r*	I_r*	I_r†
Air	1.00	1.00	1.00	N_2O	1.53	1.02	
A	1.24		1.38	NH_3	0.81	0.90	
Br	3.90			CO	1.00	1.02	
H_2	0.23	0.99	1.07	CO_2	1.55	1.02	
He	0.22		1.26	CCl_4	5.30	1.32	
Kr			1.53	CS_2	2.99	1.38	
N_2	0.94‡	0.96	0.98	C_2N_2	1.93		
Ne			1.28	$CHCl_3$	4.08§	1.29	
O_2	1.14	1.13	1.08	CH_3Br	2.75	1.32	
Xe			1.68	CH_3I	3.43§	1.33	
HCl		1.29		CH_4	1.06	1.18	
HBr		1.29		CH_4O	1.74	1.22	
HI		1.29		C_2H_2	1.40	1.26	
SO_2	2.02	1.03		C_2H_4	1.65	1.22	
NO	1.28			C_2H_4O‖	2.14	1.05	

TABLE 9.—(*Continued*)

Gas	Ra		Po	Gas	Ra		Po
	C_r*	I_r*	I_r†		C_r*	I_r*	I_r†
C_2H_5Cl	3.10	1.29		C_4H_{10}‖	4.02		
C_2H_5I	4.00	1.28		$C_4H_{10}O$‖	4.40	1.33	
C_2H_6	2.02	1.30		C_5H_{12}‖	4.85	1.35	
C_2H_6O‖	2.46	1.23		C_6H_6‖	4.30	1.29	
C_3H_8	3.05						

* From (8, 9, 17, 37, 38, 39, 43, 46, 60, 61). † From (30, 62).
‡ Another observer (9) finds 0.24 for α from Ra-C′.
§ Strutt (60) finds 4.44 for $CHCl_3$, and 3.51 for CH_3I.
‖ C_2H_4O = acetaldehyde, C_2H_6O = ethyl alcohol, C_4H_{10} = butane, $C_4H_{10}O$ = ethyl ether, C_5H_{12} = pentane, C_6H_6 = benzene.

TABLE 10.—IONIZATION OF GASES BY ACCELERATED POSITIVE RESIDUES: VARIATION WITH INTENSITY (X) OF FIELD

The ionization is produced by the positive residues which result from ionizing the gas by impact of electrons. Unit of $X = 1$ volt/cm; of $p = 1$ mm of Hg; of $\beta = 1$ per cm.

X/p	$100\beta/p$			
	A	H_2	He	Air
610	24.5			
600	21.5			10.0
520	14.9			6.4
500	13.8			5.6
450	11.6			3.8
400	9.5			2.3
350	7.0	33.0		1.4
300	5.3	26.4		0.62
250	3.8	17.8		0.28
200	2.0	8.2	16.5	0.20
180	1.4	5.9	13.9	0.18
160	0.85	4.1	11.3	0.12
140	0.50	2.6	9.0	0.10
120	0.40	1.60	7.0	
100	0.30	1.03	5.4	
80	0.20	0.64	4.0	
50	0.10	0.20	2.0	
30			1.0	
Lit.	(25)	(64, 68)	(26)	(25, 63, 64, 68)

TABLE 11.—ATOMIC IONIZATION RELATIVE TO AIR

If C_r = coefficient of molecular ionization of the gaseous compound $F_f G_g H_h$ relative to air, and $E_r = E_i/E_{ia}$, where E_{ia} = value of E_i for air, then, in many cases, quite approximately $C_r = fc_f + gc_g + hc_h$ and $E_r = fe_f + ge_g + he_h$, where c_f, c_g, c_h and e_f, e_g, e_h are numbers characteristic of the several constituent species of atoms. The c's are called the atomic ionization relative to air. The atomic stopping power is ec.

Atom	α-particles; Ra		β-rays; U-X	γ-rays	γ, Zn*
	e	c	c	c	c
Br	0.685	1.72	2.67	2.81	4.71
C	0.894	0.51	0.46	0.46	0.44
Cl	0.676	1.16	1.44	1.44	1.50
H	0.754	0.175	0.18	0.18	0.18
	1.14†	0.116†			
I	0.658	2.26	4.10	4.50	10.88
N	1.05	0.47	0.475	0.45	0.41
Ni				1.82	2.56
O	0.962	0.55	0.58	0.58	0.57
S	0.603	1.24	1.60	1.60	1.48
Lit.	(38)	(38)	(37)	(37)	(37)

* Secondary rays from Zn. † Pure atomic H.

TABLE 12.—RELATIVE MOLECULAR IONIZATION OF GASES BY γ-RAYS AND X-RAYS

See also Table 13. $n_r \equiv n/n_a = C_r p T_a/p_a T$; n_a, p_a, T_a refer to air. $E_r = (E_i)_{gas}/(E_i)_{methyl\ acetate}$. R_{sec} = relative amount of secondary radiation emitted by the gas. Soft X-rays are those stopped by 0.3 mm Pb; hard X-rays are those which pass through 0.3 mm Pb (45).

Gas	γ-rays, C_r						X-rays				
	Primary		Secondary				C_r		R_{sec}	E_r	
	Ra	Ra	Ra	C	Pb	Zn	Hard	Soft		Hard	Soft
Air	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
H_2	0.169	0.19	0.160	0.084	0.139	0.088	0.177*	0.105*			
								0.114†			
							0.18		0.12		
O_2	1.17		1.16	1.18	1.07	1.11	1.17*	1.30*			
								1.39‡			
SO_2§	2.13		2.27	2.49		2.17	4.79*	11.05*			
							2.3‖	7.97‖	4.10		
H_2S		1.23									
N_2O			1.55			1.34		1.47	1.53		
NH_3			0.90	0.92	0.914						
CO_2§	1.53		1.58	1.58	1.55	1.53	1.49	1.57			
							1.33*	1.46*			
								1.60†			
							1.33*		1.54*		
CCl_4	5.67	5.6	6.33	6.00	6.16	6.35	71.0	67.3	8.6	0.7	0.89
								45.3†			
CS_2			3.66	3.43	3.31	3.40					
$CHCl_3$	4.88	4.8	4.93	5.08		5.20		31.9†			
CH_3Br			3.81	6.47	5.83	6.15		71.0	215		
CH_3I	4.80	5.2	5.37	15.19	10.36	12.07	125	145	41.5	1.0	0.52
								72†			
C_2N_2	1.71										
C_2H_2				1.24		1.20					
C_2H_4O			2.17			2.16					
C_2H_5Br			4.63	6.30		6.05	118	72	217	0.7	0.86
C_2H_5Cl			3.19			3.39	17.3	18.0	3.2	1.00	0.61
C_2H_5I			6.47	15.60		12.46					
$C_3H_6O_2$¶							3.90	4.95	2.72	1.00	1.00
$C_4H_{10}O$¶			4.29	4.35	4.34	4.29					
C_5H_{12}¶			4.53		4.17	4.36					
$Hg(CH_3)_2$								425			0.69
$Ni(CO)_4$§			5.98			6.60	97	89	8.1	1.1	0.57
Lit	(60)	(17)	(8)	(8)	(8)	(8)	All (12, 13) except as indicated.				

* (45). † (60). ‡ (48). ‖ (17). § *See also* Table 13. ¶ $C_3H_6O_2$ = methyl acetate, $C_4H_{10}O$ = ethyl ether, C_5H_{12} = pentane.

TABLE 13.—RELATIVE MOLECULAR AND TOTAL (I_r) IONIZATION OF GASES BY SECONDARY X-RAYS

See also Table 12. $n_r \equiv n/n_a = C_r p T_a/p_a T$; n_a, p_a, T_a refer to air. Unit of p = 1 mm of Hg

Gas	CO_2		SO_2		SeH_2
Radiator	C_r	I_r	C_r	I_r	I_r
Ag					231
As	1.510	0.91	11.73	1.22	
Cu	1.552	0.89	11.84	1.08	29.2
Fe	1.581	0.90	11.34	1.07	30.3
I					286
Mo	1.541	0.92	11.45	1.00	190
Ni	1.546	0.88	11.57	1.25	
Se	1.533	0.86	11.76	1.11	30.6
Sn					250
Sr	1.527	0.94	11.81	1.04	122
Zn	1.538	0.91	11.52	1.18	
Lit	(49)	(49)	(49)	(49)	(1)

TABLE 14.—ENERGY (E_i) EXPENDED IN IONIZING GASES

For X-rays, Kulenkampff (41) finds $E_i = (5.56 \pm 0.79) \times 10^{-11}$ erg per ion-pair and independent of wave-length (λ) if $0.56 < \lambda < 2$ Å. At shorter wave-lengths others find $E_i = ae^{-b\lambda}$; for air $a = 2.2 \times 10^{-10}$ erg per ion-pair, $b = 5.08$ Å^{-1}. In the table, E_i = observed value from which V_i is computed by relation $E_i = eV_i$. Unit of $\lambda = 1$ Å; of $E_i = 10^{-11}$ erg per ion-pair; of $V_i = 1$ volt.

(1) X-rays; air

λ	E_i	V_i	Lit.	λ	E_i	V_i	Lit.
0.56	1.25	7.86	(7)	0.275	5.37*	33.7	(29, 40)
0.397	2.97*	18.6	(29, 40)	0.205	7.57*	47.5	(29, 40)
0.333	3.54*	22.2	(29, 40)	0.166	9.57*	60.1	(29, 40)
0.325	4.33	27.2	(7)				

* Published in arbitrary units and here reduced to basis of others by dividing by the empirical factor 3.50×10^{-11}.

TABLE 14.—(*Continued*)
(2) α-rays from Po (30)

Gas	E_i	V_i	Gas	E_i	V_i
A	3.8	24	N_2	5.25	33
H_2	4.9	31	Ne	4.12	25.9
He	4.17	26.2	O_2	4.86	30.5
Kr	3.43	21.5	Xe	3.12	19.6

TABLE 15.—IONIZATION OF GASES MIXED WITH VAPOR OF P (59)

The gas is in equilibrium with a liquid containing P. For column "*A*" the liquid is almond oil; for "*W*" it is H_2O. *See also* (28, 31, 47, 58).

Relative ionizations

Gas	*A**	*W**	Gas	*A**	*W**
Air	1.0	1.0	CO_2	59.6	28.7
H_2	48.2	15.3	N_2O		22.1
O_2	5.5	2.9			

* For air, the ionization over *W* is 2.16 times that over *A*; this ratio probably depends upon the relative amounts of P and upon its state of dispersion in the two liquids.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Anslow, *2*, **25**: 484; 25. (2) Bianu, *Bull. acad. Roumaine*, **9**: 115; 24. (3) Bishop, *63*, **12**: 1148; 11. (4) Bloch, *3*, **38**: 559; 12. (5) Bohr, *3*, **25**: 10; 13. (6) Bohr, *3*, **30**: 581; 15. (7) Boos, *96*, **10**: 1; 22. (8) Bragg, *3*, **13**: 333; 07. (9) Bragg, *Studies in radioactivity*, p. 65. New York, Macmillan, 1912. (10) Bronson, *5*, **78**: 494; 07. (11) Clo, *21*, **33**: 115; 11. (12) Crowther, *3*, **14**: 653; 07. (13) Crowther, *5*, **82**: 103; 09. (14) Crowther, *5*, **82**: 351; 09. (15) Durack, *3*, **4**: 29; 02. (16) Durack, *3*, **5**: 550; 03. (17) Eve, *3*, **8**: 610; 04. (18) Eve, *3*, **22**: 551; 11. (19) Fowler, *201*, **21**: 521; 23. (20) Fowler, *3*, **47**: 257; 24. (21) Geiger, *5*, **82**: 486; 09. (22) Geiger, *5*, **83**: 505; 10. (23) Geiger, *96*, **8**: 45; 22. (24) Geiger and Kovarik, *3*, **22**: 604; 11. (25) Gill and Pidduck, *3*, **16**: 280; 08. (26) Gill and Pidduck, *3*, **23**: 837; 12. (27) Glasson, *3*, **22**: 647; 11. (28) Gockel, *63*, **4**: 599; 03. (29) Grebe and Kriegmann, *96*, **28**: 91; 24. (30) Gurney, *5*, **107**: 332; 25. (31) Harms, *63*, **5**: 93; 04. (32) Herweg, *3*, **19**: 333; 06. (33) Horton, *3*, **34**: 461; 17. (34) Hughes and Klein, *2*, **23**: 450; 24. (35) Jesse, *2*, **26**: 208; 25. (36) Johnson, *2*, **10**: 609; 17. (37) Kleeman, *5*, **82**: 358; 09. (38) Kleeman, *5*, **84**: 16; 11. (39) Kleeman, *5*, **79**: 220; 07. (40) Kriegesmann, *96*, **32**: 542; 25. (41) Kulenkampff, *3*, **79**: 97; 26. (42) Kulenkampff, *3*, **80**: 261; 26. (43) Laby, *5*, **79**: 206; 07. (44) McClung, *3*, **7**: 81; 04. (45) McClung, *3*, **8**: 357; 04. (46) Metcalf, *3*, **18**: 878; 09. (47) Meyer and Müller, *88*, **6**: 332; 04. (48) Moseley and Robinson, *3*, **28**: 327; 14. (49) Owen, *5*, **86**: 426; 12. (50) Palmer, *2*, **32**: 1; 11. (51) Partzsch, *3*, **40**: 157; 13. (52) Rutherford, *3*, **10**: 163; 05. (53) Rutherford, *3*, **12**: 134; 06. (54) Rutherford, *3*, **13**: 110; 07. (55) Rutherford, *Radioactive substances and their radiations*, p. 579. London, Cambridge Univ. Press, 1913. (56) Rutherford, *3*, **47**: 277; 24. (57) Samuel, *96*, **29**: 209; 24. (58) Schenck, Mihr and Bauthien, *26*, **39**: 1506; 06. (59) Schmidt, *63*, **14**: 120; 13. (60) Strutt, *5*, **72**: 208; 04. (61) Taylor, *3*, **21**: 571; 11. (62) Taylor, *3*, **26**: 402; 13. (63) Townsend, *Theory of ionization of gases by collision*. London, Constable, 1910. (64) Townsend, *3*, **6**: 598; 03. (65) Townsend, *3*, **45**: 1071; 23. (66) Townsend and Ayres, *3*, **47**: 401; 24. (67) Townsend and Bailey, *3*, **46**: 657; 23. (68) Townsend and Hurst, *3*, **8**: 738; 04. (69) Townsend and McCallum, *3*, **47**: 737; 24. (70) Williamson, *2*, **21**: 107; 23. (71) Wilson, *5*, **85**: 240; 11.

ELECTRICAL RESISTANCE OF ELEMENTARY SUBSTANCES AT TEMPERATURES BELOW −80°C*

H. KAMERLINGH ONNES AND W. TUYN

CONTENTS

Resistance of pure elementary substances at various temperatures below −80°C. 125
Resistance of three platinum wires between −80 and −270°C. 130
Effect of impurities, heat treatment, tension, compression, etc. 131
(For symbols which are not here defined, *see* Vol. I, p. 16.)

MATIÈRES

Résistance des substances élémentaires pures à des températures variées inférieures à −80°C.
Résistance de trois fils de platine entre −80 et −270°C.
Effet des impuretés, traitement thermique, tension, compression, etc.
(Pour les symboles qui ne sont pas expliqués ici, *voir* Vol. I, p. 16.)

INHALTSVERZEICHNIS

Widerstand elementarer reiner Stoffe bei verschiedenen Temperaturen unterhalb −80°C.
Widerstand von drei Platindrähten zwischen −80 und −270°C.
Einfluss von Verunreinigungen, Wärmebehandlung, Dehnung, Druck, u.s.w.
(Zeichen, welche nicht hier, definiert sind, *siehe* Bd I, S. 16.)

INDICE PAGE

Resistenza di elementi puri a varie temperature al di sotto di −80°C. 125
Resistenza di tre fili di platino fra −80 e −270°C. 130
Effetto delle impurezze, trattamento termico, tensione, compressione, ecc. 131
(Per i simboli che non sono qui definiti, *vedi* Vol. I, p. 16.)

As it is impracticable to determine the volume resistivity at very low temperatures, merely the ratio of the resistance of a given specimen at a given temperature to the resistance of the same specimen at 0°C is given; except that in a few cases the actual resistance of the specimen at each of a series of low temperatures is given, instead of its ratio. Extremely low temperatures are occasionally expressed in terms of the pressure of saturated helium vapor at the same temperatures; this is especially convenient for those cases in which a small change in temperature is accompanied by a great change in the resistance.

If the resistances of a number of impure specimens (1, 2, . . . *n* . . .) of the same metal, all of the same dimensions at 0°C, are measured at a series of temperatures, and if the observations are plotted in rectangular coordinates (R_{nt} *vs.* t) and are connected by smooth curves, a curve for every specimen, then it is found (133) that these curves differ, roughly, solely by a displacement parallel to the axis of R, and that the purer the specimen the more nearly does its resistance approach zero as t approaches the absolute zero. The composite curve obtained by displacing these curves parallel to the axis of R until they all pass through the point $R = 0$ at the absolute zero is called the curve corresponding to a specimen of the metal of "ideal" purity and condition, and of the same dimensions at 0°C as the actual specimens. If the resistances corresponding to the points upon this "ideal" curve be denoted by R_{it} and if $p_n x_n$ is the displacement which makes the curve corresponding to specimen n coincide with the "ideal" curve, then

$$R_{x_n t} = R_{it} + p_n x_n$$

If x_n is the percentage of admixed impurity, p_n has a large value which, over a certain temperature range, is independent of t, but depends upon the nature and the amount of the impurity, and upon the state, or condition, of the specimen (133).

Expressions which are independent of the actual dimensions of the specimens may be obtained by dividing each equation by the

* Published in somewhat greater detail in (141).

resistance of the specimen at 0°C. Doing this, writing $p_n' x_n$ for $p_n x_n / R_{x_{n0}}$, and remembering that $R_{i0}/R_{x_{n0}} = 1 - p_n' x_n$ we find (17, 18)

$$\frac{R_{x_n t}}{R_{x_n 0}} = \frac{R_{it}}{R_{i0}}(1 - p_n' x_n) + p_n' x_n$$

and

$$\Delta\left(\frac{R}{R_0}\right) = \frac{R_{x_2 t}}{R_{x_2 0}} - \frac{R_{x_1 t}}{R_{x_1 0}} = \frac{p_2' x_2 - p_1' x_1}{1 - p' x_1}\left(1 - \frac{R_{x_1 t}}{R_{x_1 0}}\right) = a\left(1 - \frac{R_{x_1 t}}{R_{x_1 0}}\right)$$

where a is independent of t. This is Nernst's rule (106, 108). The exactness with which it represents the observations depends upon the value of a; between 0 and −200°C departures may amount to those corresponding to errors of 0.05 to 0.20°C in the temperature (86, 146, 147). For temperatures above −208°C for Au and above −216°C for Pt, a closer approximation, to at least 0.02°C (17, 18), is given (62, 63, 64, 65) by

$$\Delta\left(\frac{R}{R_0}\right) = M\left\{\frac{R_{x_2 t}}{R_{x_2 0}} - 1\right\} + N\left\{\frac{R_{x_2 t}}{R_{x_2 0}} - 1\right\}^2$$

Various expressions, several of which are based upon the quantum theory, have been proposed for the variation of the resistance with the temperature. Only one or two examples can be given here. For monatomic metals at low temperatures, Grüneisen (43, 44, 45) finds that quite closely $R \propto T c_p$, or $R \propto T \frac{c_p}{c_v} f(T/\theta)$, and at intermediate temperatures $R \propto T\{1 + a_1 T + a_2 T^2\} f(T/\theta_r)$ (44); T, c_p, and c_v have their usual significance (Vol. I, p. 16), and θ and θ_r are temperatures characteristic of the substance. Other examples will be found in (12, 60, 61, 96, 106, 112, 163); *see also* (141).

If M is the molecular weight of a substance, the volume of M grams of the substance may be called its gram-molecular volume, and the length of one edge and the area of one face of a cube having a volume equal to its gram-molecular volume may be called its gram-molecular length and its gram-molecular area, respectively. Likewise, the resistance between opposite faces of a cube containing one gram-molecular volume of the substance may be called its gram-molecular resistivity; and, if uniformly distributed over the area, the amount of current which passes normally through a plane section of one gram-molecular area may be called the gram-molecular surface density of the current. Gram-atomic quantities are defined in a similar manner.

For all elements having the same constellation of outer electrons, the gram-atomic conductivity seems to be the same at those respective temperatures for which T/θ_r has a given value (5, 38, 46, 151, 162), or as Epstein claims, at those which are the same fraction of the absolute melting points (36). Cassel (16) claims that for such elements a more nearly correct statement is: The gram-atomic surface density of the current for a gradient of 1 volt/cm (which he calls the atomic current strength) is the same at those respective temperatures for which T/θ_r has a given value.

At temperatures below −192°C, the order of the curves of R/R_0 *vs.* t agrees with that of the values of $h\nu/k$, where ν is a frequency calculated from the specific heats of the elements (146, 147).

For complete bibliography, arranged by elements, *see* p. 134.

Table 1.—Electrical Resistance of Elementary Substances at Temperatures below −80°C

R, R_0 = resistance (not resistivity) of the specimen at t, °C, at 0°C. d = diameter of wire, i = current. Italicized numbers are actual results of observations, others are obtained by interpolation. t = centigrade temperature, °C; every t is negative.

For footnotes to table, *see* p. 130.

Ag (22, 133)

$-t$	$100R/R_0$
80	67.8
100	59.6
103.81	*58.087*
120	51.4
139.87	*43.282*
140	43.2
160	34.8
180	26.3
183.57	*24.679*
195.17	*19.703*
200	17.6
204.67	*15.528*
220	9.2
240	2.6
252.92	*0.8913*
259.22	*0.6942*

Second sample (135)

270.3	No*†

Al (78, 79, 83)

78.3	*64.80*
80	64.1
100	55.2
120	46.4
140	37.7
160	28.9
180	20.2
191.9	*14.85*
192.9	*14.49*
200	12.0
220	7.1
240	4.9
253	*4.27*

Second sample (157, 160)

271.68	*6.8*

Au‡ (14, 17, 18); *see* Fig. 1

80	68.406
84.97	*66.443*
90	64.456
100	60.506
102.22	*59.628*
105	58.531
110	56.552
115	54.572
120	52.592
125	50.607
127	49.813
130	48.619
130.28	*48.507*
135	46.625
140	44.626
143	43.424
145	42.619
145.86	*42.273*
148	41.410
150	40.602
155	38.578
160	36.549
162	35.735
164	34.919
164.37	*34.764*
166	34.102
168	33.282

Au.—(*Cont'd*)

$-t$	$100R/R_0$
170	32.460
172	31.635
174	30.807
176	29.977
178	29.145
180	28.311
182	27.475
183.95	*26.660*
184	26.639
186	25.800
188	24.958
190	24.114
192	23.268
194	22.420
195.88	*21.622*
196	21.571
198	20.720
200	19.867
202	19.013
204	18.157
205.31	*17.596*
206	17.300
208	16.442
208.18	*16.365*
210	15.584
212	14.728
214	13.872
216	13.017
216.26	*12.906*
218	12.163
220	11.310
221	10.884
222	10.459
222.78	*10.130*
223	10.035
224	9.613
225	9.194
226	8.779
227	8.368
228	7.962
228.73	*7.680*
229	7.561
230	7.165
231	6.775
232	6.391
233	6.014
233.62	*5.804*
234	5.644
235	5.282
236	4.928
236.80	*4.667*
237	4.583
238	4.247
239	3.921
240	3.605
240.25	*3.538*
241	3.300
242	3.007
243	2.727
243.68	*2.553*
244	2.461
245	2.210
245.80	*2.039*
246	1.974
24	1.757

Au.—(*Cont'd*)

$-t$	$100R/R_0$
248	1.558
249	1.376
250	1.209
251	1.056
252	0.918
252.57	*0.845*
253	0.794
254	0.685
255	0.591
255.01	*0.594*
256	0.512
257	0.447
258	0.394
258.35	*0.379*
259	0.351
260	0.317
261	0.290
262	0.269
263	0.253
264	0.242
265	0.234
266	0.229
267	0.226
268	0.224
268.88	*0.223*
269	0.223
269.57	*0.223*
270	0.223
270.84	*0.223*
271	0.223
271.61	*0.223*

Single crystal (104, 105)

191.37	*23.20*
193.14	*22.52*
200	19.5
220	10.9
240	3.3
252.69	*0.642*
260	0.10
268.89	*0.039*
269.38	*0.038*
271.48	*0.039*

Bi (22, 133)

80	71.3
100	64.8
103.71	*63.649*
120	58.6
139.88	*52.865*
140	52.8
160	47.3
164.05	*46.246*
180	42.1
182.73	*41.435*
195.17	*38.478*
200	37.2
204.68	*36.064*
216.01	*33.014*
220	32.0
240	26.7
253.01	*22.329*
255.34	*21.388*
258.86	*19.574*

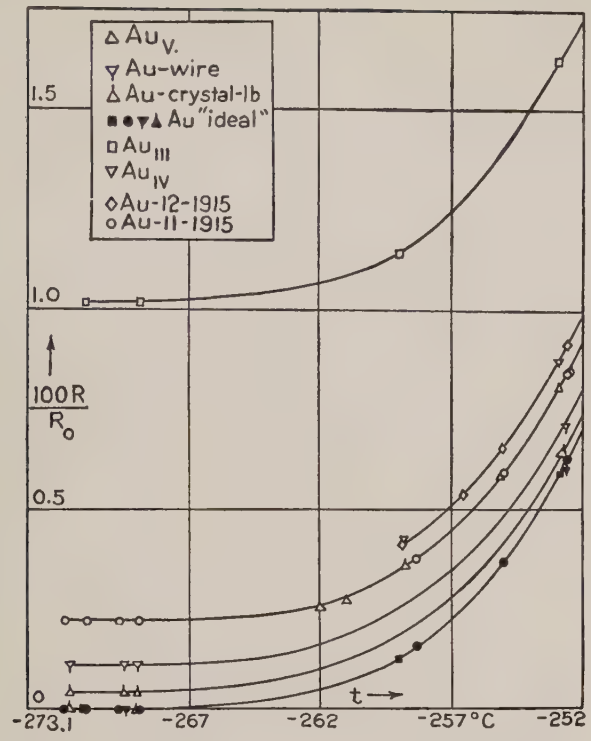


FIG. 1.—Gold: Variation of R with temperature.

Au_{III} [22, 116, 133], Au_{IV} [22, 133], Au-12-1915 [17, 18], Au-11-1915 [16, 17, 18], Au_V [22, 133], Au-wire [104], Au-crystal-1b [104, 105]. The last two are from Meissner. For meaning of "ideal," *see* p. 124.

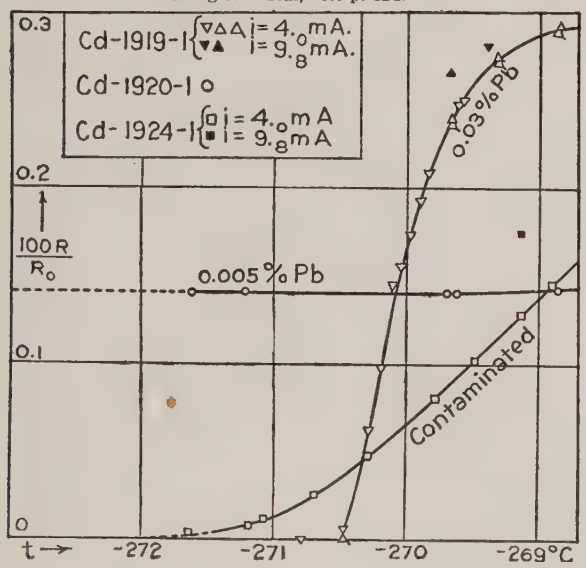


FIG. 2.—Cadmium: Variation of R with temperature (t) and current (i) [157, 160].

Wires extruded from Kahlbaum Cd; "1919" is from old material; "1924" was drawn through a die contaminated with Pb.

Bi.—(*Cont'd*)	
Second sample [135]	
$-t$	$100R/R_0$
268.84	No*†
Single crystal [11]§	
⊥80	69.3
92.1	*66.3*
100	64.4
120	59.4
128.1	*57.1*
140	53.5

Bi.—(*Cont'd*)	
$-t$	$100R/R_0$
149.1	*50.5*
157.1	*47.2*
‖80	75.4
96.1	*72.0*
100	71.3
120	67.6
124.1	*66.9*
140	64.0
160	60.4

Bi.—(*Cont'd*)	
$-t$	$100R/R_0$
161.1	*60.2*
C	
Graphite [135, 145]	
78	*92*
80	92
120	86
160	77
179	*71*
200	61

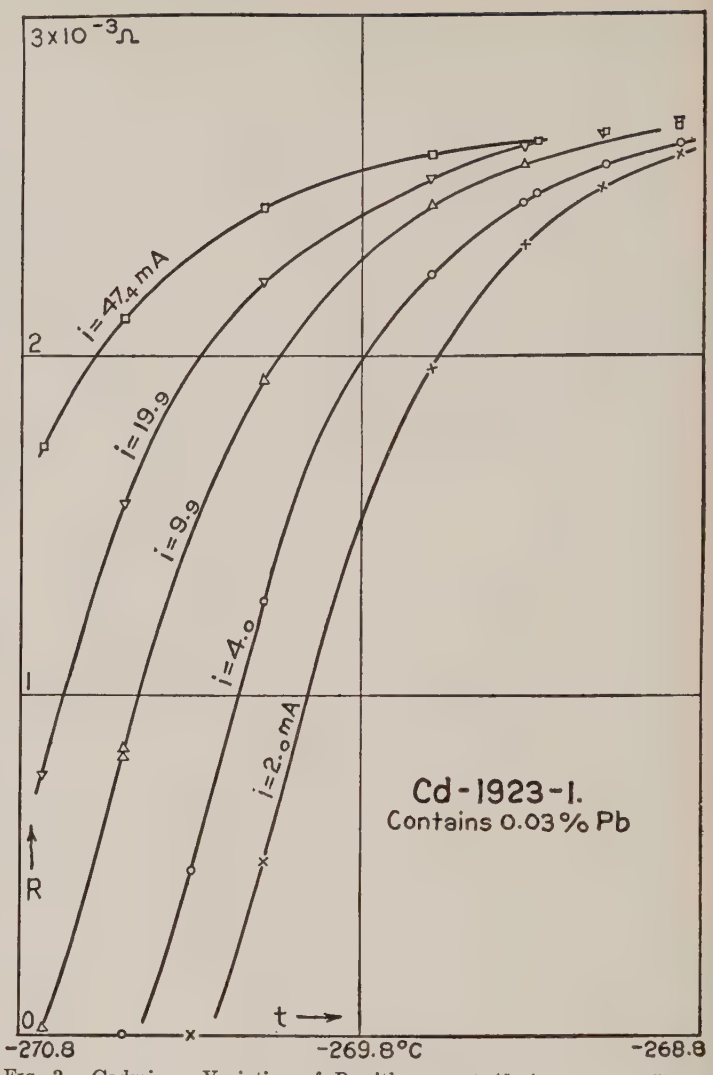


FIG. 3.—Cadmium: Variation of R with current (i) [157, 160]. From old material.

C.—(*Cont'd*)	
$-t$	$100R/R_0$
240	28.5
253.1	*15.8*
258.9	*9.5*
Carbon [22, 134]	
80	114
102.99	*115.89*
120	117
160	119
200	120
240	122
252.93	*122.52*
255.13	*123.95*
Cd [157, 159, 160]; *cf.* [78, 83]; *see* Figs. 2, 3	
78.3	*69.08*
80	68.6
100	60.5
120	52.7
140	45.1
160	37.5
180	29.85
182.68	*28.820*

Cd.—(*Cont'd*)	
$-t$	$100R/R_0$
192.08	*25.125*
200	21.96
200.03	*21.967*
207.10	*19.158*
216.32	*15.475*
220	14.0
240	6.2
252.58	*2.267*
255.03	*1.666*
256.56	*1.331*
258.87	*0.907*
260	0.725
268.87	*0.143*
269.63	*0.141*
269.70	*0.141*
271.22	*0.140*
271.69	*0.140*
Single-crystal§ [47, 48]	
⊥78.2	69.3
80	68.5
100	60.3
120	52.4

Cd.—(*Cont'd*)	
$-t$	$100R/R_0$
140	44.7
143.15	*43.5*
160	37.1
180	29.4
183.4	*28.3*
188.1	*26.2*
188.9	*26.0*
189.8	*25.6*
191.1	*25.0*
200	21.4
220	13.5
240	5.9
252.67	*1.87*
252.72	*1.86*
‖78.2	69.4
80	68.5
100	60.7
120	53.0
140	45.3
143.15	*43.9*
160	37.6
180	30.0
183.4	*29.1*

Cd.—(*Cont'd*)

$-t$	$100R/R_0$
184.8	*28.2*
188.1	*27.0*
190.1	*26.3*
191.1	*25.8*
200	22.2
220	14.3
240	6.8
252.67	*2.204*
252.72	*2.207*

Co (80); *cf.* (146, 147)

80	57.4
100	48.2
120	40.0
140	32.3
160	24.8
180	17.4
192	*13.5*

Cs (57)

75	*65.9*
80	63.9
100	56.0
120	48.6
140	41.9
160	35.6
180	29.5
190	*26.4*

Cu (65, 69)

76	*65.739*
80	64.9
100	55.7
120	46.5
140	37.3
160	28.6
180	20.1
183	*18.868*
200	11.7
220	4.7
240	1.2
252.8	*0.6291*

Second sample (137)

272.0	No*‖

Single crystals¶ (157, 159, 160)

180	19.5
184.53	*17.49*
192.04	*14.40*
199.98	*11.03*
200	11.0
206.94	*8.40*
218.09	*4.69*
220	4.05
240	0.74
252.57	*0.154*
255.07	*0.129*
256.63	*0.109*
258.77	*0.097*

Fe (78, 79, 83)

78.1	*57.865*
80	56.9
100	47.3
120	38.1
140	29.2
160	20.7

Fe.—(*Cont'd*)

$-t$	$100R/R_0$
180	13.1
192.7	*8.48*
200	6.2
220	2.7
240	1.45
253	*1.13*

Second sample (137)

272.0	No* **

Ga (157, 160)

271.5	No* ††

Ge (8)

79	*82.75*
80	82.3
95	*80.3*
100	80.3
108	*79.3*
112	*80.9*
113	*79.7*
117	*80.4*
120	80.7
140	83.8
155	*86.1*
160	89.2
168	*91.8*
177	*96.9*
180	96.5
183	*98.8*
185	*99.3*
193	*106.8*

Second sample (157, 160)

270.74	No * ††

Hg‡‡ (137); for superconductivity, *see* (56, 113, 114, 115, 117, 152); *see* Figs. 4 and 5

80	67.1
88.17	*63.72*
100	58.8
107.29	*55.86*
118.87	*51.31*
120	50.9
131.26	*46.60*
140	43.4
140.37	*43.29*
150.28	*39.82*
156.57	*37.65*
160	36.4
180	29.5
182.96	*28.51*
192.17	*25.37*
200	22.8
220	16.0
240	9.1
252.70	*4.904*
255.20	*4.072*
257.31	*3.354*
258.52	*2.946*
260	0.245
268.76	*0.206*
268.80	*0.200*
268.86	*0.188*
268.94	*0.176*

Hg.—(*Cont'd*)

Second sample

Figs. 4, 5	Yes*

In (157, 158, 159); *see* Figs. 6, 7

$-t$	$100R/R_0$
182.79	*28.759*
194.06	*24.922*
200	22.88
202.07	*22.202*
209.98	*19.527*
218.30	*16.717*
220	16.15
240	14.5
252.65	*5.739*
254.95	*5.173*
256.61	*4.796*
258.89	*4.317*
260	4.1
268.87	*3.394*
269.49	*3.392*
269.61	*3.387*
269.67	*3.387*‖‖

V. p. He‖‖ ¶¶

309.8	*3.387*
308.7	*3.385*
307.4	*2.02*
306.9	*0.67*
306.0	Yes*

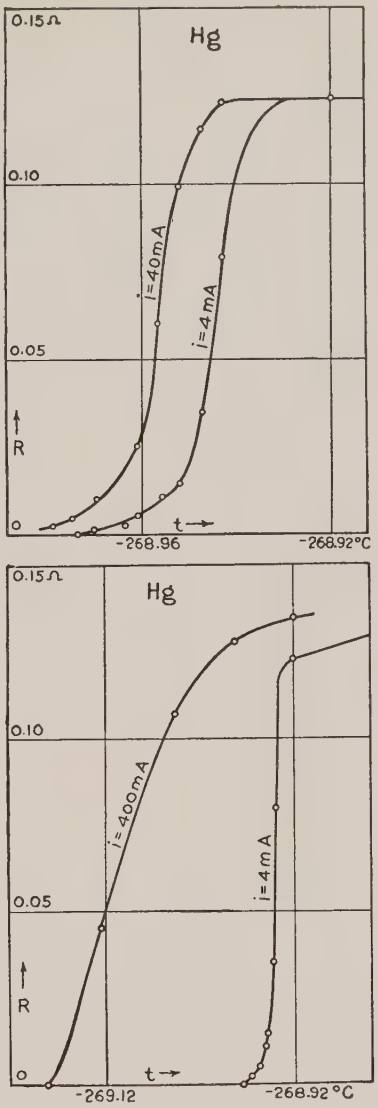
d = 0.17mm; i = 4.0mÅ

Ir (78, 83)

78.4	*69.22*
80	68.6
100	60.6
120	52.5
140	44.4
160	36.0
180	27.5
191.9	*22.57*

K (164, 165)

80	65.8
100	57.7
102.22	*56.88*
120	50.1
140	42.7
160	35.6
164.37	*33.87*
180	28.4
182.6	*27.47*
182.95	*27.19*
200	21.1
200.2	*21.11*
200.96	*20.70*
216.32	*15.14*
216.75	*15.14*
220	13.8
240	6.6
252.54	*2.708*
252.74	*2.703*
254.69	*2.213*
255.97	*1.943*
256.77	*1.787*
258.89	*1.434*



FIGS. 4, 5.—Mercury: Variation of R with current (i) (117).

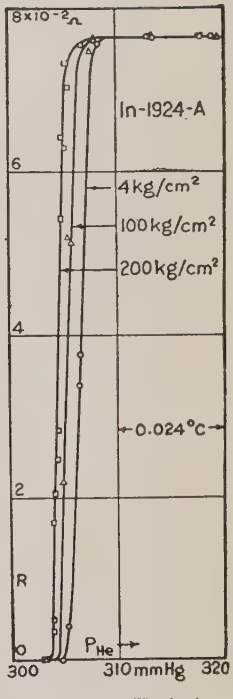


FIG. 6.—Indium: Variation of R with pressure and temperature (152, 154).

K.—(*Cont'd*)

$-t$	$100R/R_0$
258.96	*1.429*
260	1.29
268.9	*0.702*
269.6	*0.697*
270.9	*0.695*

Li (103); *cf.* (52, 54)

80	62.3
100	53.0
120	44.0
140	35.2
160	26.6
180	18.3
182.20	*17.37*
192.95	*13.06*
200	10.4
220	4.4
240	1.2
252.67	*0.73*

Li.—(*Cont'd*)

$-t$	$100R/R_0$

Second sample (138)

271.43	*3.45*

Mg (28)

78.3	*68.2*
80	67.4
100	59.0
120	50.5
140	41.9
160	33.2
180	24.4
182.95	*23.0*

Mo (78, 83)

78.2	*66.60*
80	65.9
100	57.4
120	48.9
140	40.5
160	32.2
180	24.2
192.5	*19.11*

Na (165)

$-t$	$100R/R_0$
80	66.0
100	57.8
102.22	*56.89*
120	49.7
140	41.7
160	33.7
164.37	*31.94*
180	25.7
182.95	*24.40*
200	17.6
200.96	*17.04*
216.32	*10.89*
220	9.4
240	3.1
260	0.45
268.9	*0.381*
269.6	*0.382*
270.9	*0.382*
271.6	*0.382*

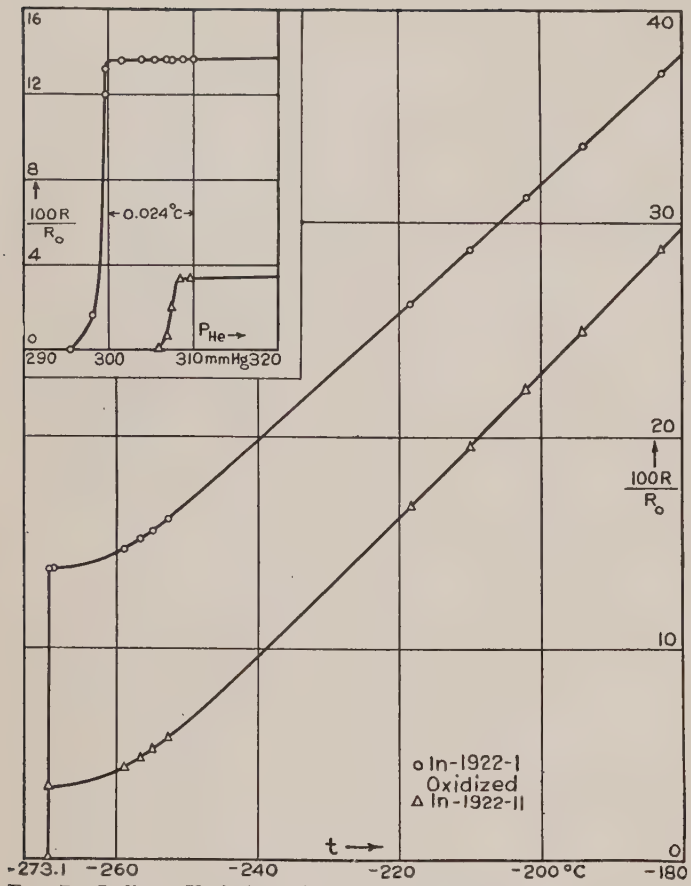


FIG. 7.—Indium: Variation of R with temperature, and effect of oxidation (157, 158, 159).

Ni (26, 40)	
$-t$	$100R/R_0$
78.3	*61.3*
80	60.5
100	51.8
120	43.7
140	36.1
160	28.7
180	21.7
182.9₅	*20.8*
200	15.6
220	11.2
240	8.9
252.7₆	*8.5₅*
Second sample (135)	
270.3	No*†

Pb‡ (140, 157, 159, 160); *cf.* (83)	
80	68.31
90	64.46
100	60.64
110	56.82
120	53.03
130	49.24
140	45.48
150	41.73
160	38.00
170	34.30
180	30.61
184.53	*28.947*

Pb.—(*Cont'd*)	
$-t$	$100R/R_0$
190	26.94
192.04	*26.171*
199.98	*23.208*
200	23.20
205	21.31
206.93₅	*20.600*
210	19.42
215	17.55
218.09	*16.384*
220	15.6₈
225	13.5₈
230	11.5₂
235	9.5₀
240	7.5₄
245	5.6₅
250	3.8₆
252.57	*3.014*
255	2.21
255.07	*2.188*
256.63	*1.715*
258.77	*1.135*
260	0.85
262.7	*0.40*
264.4	*0.18*
265	0.14
265.5	*0.11*
265.8₃	*0.10*
265.83+	Yes*

Pd (78, 79, 83)	
$-t$	$100R/R_0$
78.1	*68.51*
80	67.7
100	59.1
120	50.4
140	41.8
160	33.0
180	24.2
192.7	*18.44*
200	15.2
220	7.5
240	2.7
253	*0.93*
Pt; *see* Table 2	

Rb (57)	
78	*54.3*
80	53.5
100	46.3
120	39.9
140	34.2
160	28.8
180	23.8
190	*21.6*

Rh (78, 83)	
78.4	*65.80*
80	65.1
100	56.4
120	47.7
140	39.0

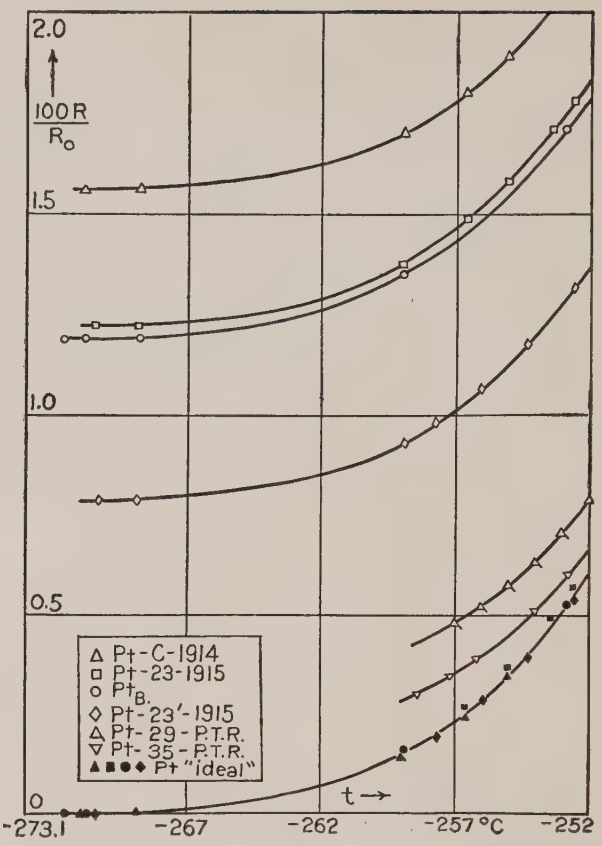


FIG. 8.—Platinum: Variation of R with temperature.

Pt-C-1914 (157, 159, 160), Pt-23-1915 (19, 87, 97, 157, 160), Pt_B (112), Pt-23'-1915 (88, 160), Pt-29-P.T.R. (65, 69, 70, 73, 75), Pt-35-P.T.R. (150). For meaning of "ideal," *see* p. 124.

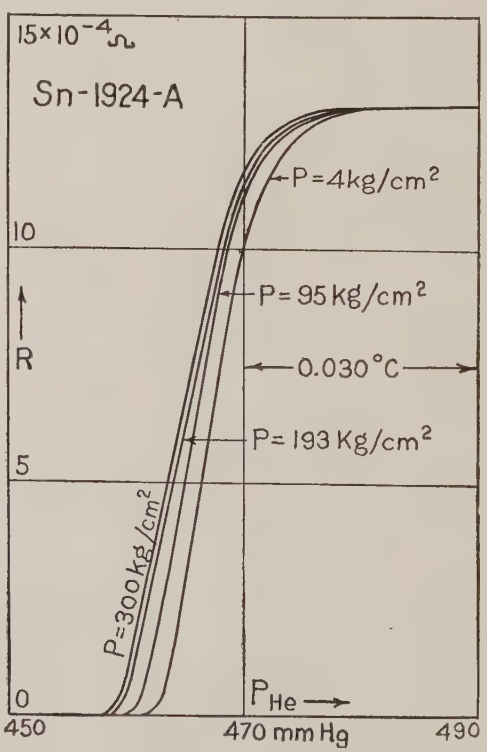


FIG. 9.—Tin: Effect of pressure (P) upon the variation of R with temperature (152, 154).

Rh.—(*Cont'd*)

$-t$	$100R/R_0$
160	30.2
180	21.4
191.9	*16.25*

Sb (41)

77	*65.73*
80	64.5
100	56.7
120	49.1
140	41.7
160	34.8
180	28.3
190	*25.03*

Single crystal§ (55)

⊥80	63.0
81	*62.6*
98.9	*54.5*
100	54.9
102.6	*53.7*
110	*50.7*
120	47.3
120.2	*47.0*
120.9	*47.3*
130	*44.3*
137	*40.8*
140	40.0
160	32.9
180	26.3
188	*23.5*
191	*22.8*

Si (93, 94)

72	*148*
80	156
100	175
116	*191*
120	195
140	219
160	248
180	282
189	*299*

Sn (14, 157, 159, 160); *see also* Figs. 9, 10, 11

80	66.1₀
100	58.0₈
102.13	*57.36₈*
115.14	*52.16₇*
120	50.2₀
127.50	*47.25₆*
140	42.2₆
141.06	*41.90₀*
158.74	*34.91₆*
160	34.63
180	26.55
182.80	*25.44₉*
194.07	*20.98₃*
200	18.65
202.07	*17.79₂*
209.98	*14.67₆*
218.30	*11.45₀*
220	10.75
240	3.80
252.65	*1.162*
254.95	*0.836*

Sn.—(*Cont'd*)

$-t$	$100R/R_0$
256.61	*0.637*
258.89	*0.409*
260	0.30
268.86	*0.100*
269.33	*0.099*
269.37	Yes*

V.p. He‖‖¶¶ (157, 160)

$-t$	$100R$
765	*0.452*
480.2	*0.443*
476.7₅	*0.423*
474.5	*0.394*
471.8	*0.327*
470.1	*0.243*
467.5	*0.129*
466.7₅	*0.112*
465.6₅	*0.067*
465.4₅	*0.070*
463.2	*0.030*
463.1	*0.024*
461.9	*0.018*
461.5	*0.007*
461.1	*0.010*
458.6	*0.003*
456.1	Yes*

d = 0.19 mm; *i* = 4.0mÅ; unit of *R* = 1 ohm

Ta (78, 83)

$-t$	$100R/R_0$
78.2	*72.98*
80	72.4
100	64.9
120	57.3
140	49.6
160	41.9
180	34.3
192.6	*29.55*

Te (4, 127)

80	77.3
100	73.2
102.3	*72.3*
110.8	*71.3*
120.0	*69.8*
131.3	*67.3*
140	65.9
160	62.6
180	59.6
183.1	*58.9*
193.1	*57.9*
200	56.7
203.6	*55.9*
220	54.7
225	54.6***
240	56.8
252.8	*60.4*
255.4	*61.4*
258.6	*62.4*

Ti (93, 94)

70	*114.6*
80	117.5
100	123.5

Ti.—(*Cont'd*)

$-t$	$100R/R_0$
120	130.6
140	139.2
160	149.6
180	161.9
191	*169.0*

Tl (139, 157, 159); *cf.* (28); *see also* Fig. 12

78.3	*67.10*
80	66.3
100	58.4
120	50.7
140	43.2
160	35.9
180	28.8
184.52	*27.20₅*
192.04	*24.52₉*
200	21.71
200.03	*21.69₂*
207.11	*19.18₇*
216.33	*15.92₉*
220	14.60
240	7.36
252.62	*3.023*
255.05	*2.286*
256.62	*1.841*
258.93	*1.259*
260	1.01
268.86	*0.084*
269.83	*0.072*
270.47	*0.069*
270.57	*0.068*‖‖
270.61	*0.066*
270.62	Yes*

d = *0.5* mm; *i* = *3.1*mÅ

W (78, 83)

78.3₅	*65.09*
80	64.4
100	55.7
120	46.9
140	38.2
160	29.5
180	20.8
192.8	*15.29*

Zn (157, 159, 160); *cf.* (78, 83)

78.2	*68.62*
80	67.8
100	59.7
120	51.6
140	43.5
160	35.3
180	27.1
184.37	*25.367*
192.05	*22.136*
200	18.8
200.38	*18.643*
206.99	*15.901*
215.26	*12.552*
220	10.8
240	4.1
252.60₅	*1.383*
255.10	*1.119*

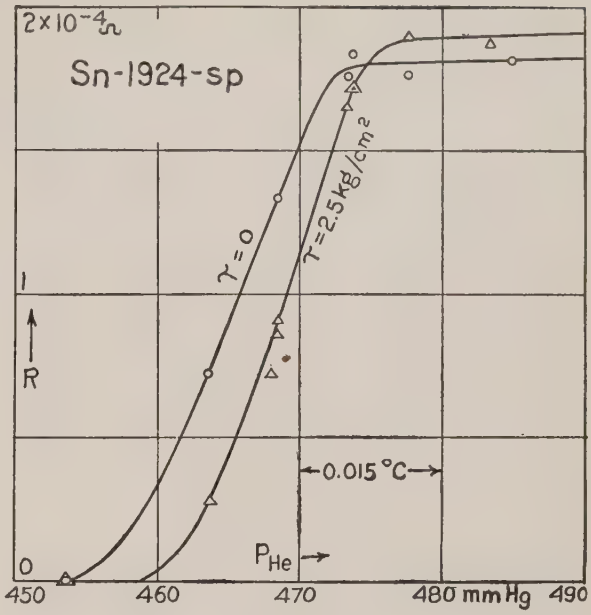


FIG. 10.—Tin: Effect of tension (τ) upon the variation of R with temperature (122, 152 154).

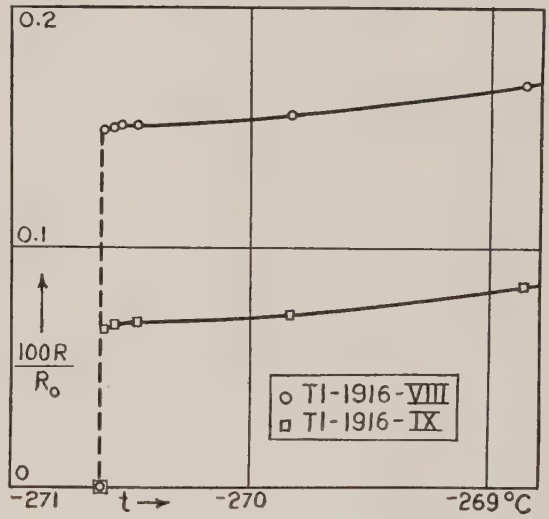


FIG. 12.—Thallium: Variation of R with temperature (139, 157).

Zn.—(*Cont'd*)

$-t$	$100R/R_0$
256.64	*0.984*
258.85	*0.838*
260	0.767
268.87	*0.378*
269.71	*0.378*
271.69	*0.378*

Single crystal§ (47, 48)

⊥*78.2*	*68.4*
80	67.6
100	59.2
120	50.7
140	42.2
143.1₅	*40.9*
160	33.9
180	25.7
188.5	*22.1*

Zn.—(*Cont'd*)

$-t$	$100R/R_0$
191.1	*21.1*
191.8	*20.7*
194.2	*19.6₅*
200	17.3
220	8.9
240	2.7
252.6₅	*0.749*
252.7₃	*0.741*
‖*78.2*	*68.1*
80	67.3
100	59.2
120	51.2
140	43.2
143.1₅	*41.8*
160	35.2
180	27.2
183.4	*26.0*

Zn.—(*Cont'd*)

$-t$	$100R/R_0$
189.1	*23.5₅*
191.1	*22.7*
191.8	*22.4*
194.5	*21.5*
200	19.3
220	11.5
240	3.7
252.7₃	*0.75₈*

Zr††† (21)

80	66.4
100	58.4
120	50.5
140	42.7
160	35.0
180	27.4
182.87	*26.26₁*
194.93	*21.85₁*

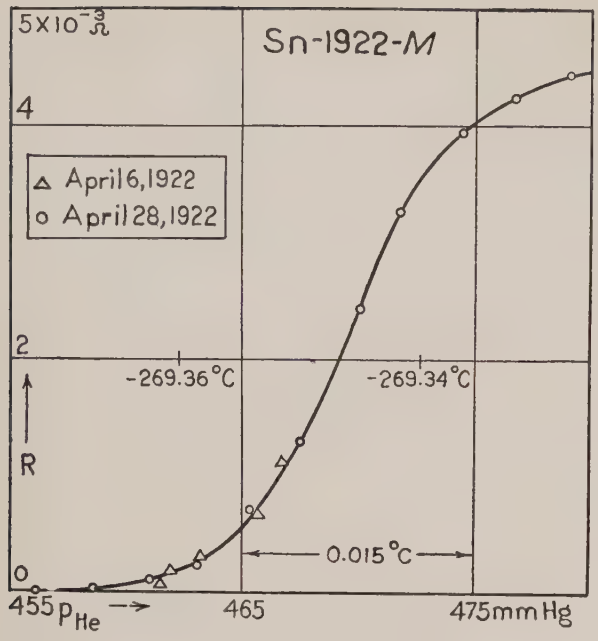


FIG. 11.—Tin: Variation of R with temperature (157, 160).

FOOTNOTES FOR TABLE 1

* No = not superconducting. Yes = superconducting. A "+" after a number in the $-t$ column indicates temperatures below that named; *e.g.*, "265.83+," means "at temperatures below −265.83°C."

† Conclusion from Hall effect.

‡ Where adjacent unitalicized entries are more than 1° apart for Au, or 5° for Pb, a linear interpolation introduces an error of less than one unit in the last figure.

§ ⊥, ∥, Denotes that the single crystal is cut or split ⊥, ∥, to the crystallographic c-axis and that the current passes ⊥, ∥, to that axis.

‖ Commercial electrolytic copper. ¶ Natural copper crystals. ** Kolswa iron.

†† Temperature deduced from vapor pressure of He (*see* Note ¶¶). For Ga, the magnetic field was 17 gauss.

‡‡ In R/R_0, the R_0 refers to solid Hg, and is obtained by extrapolation.

‖‖ Resistance R computed from observed current and potential difference, assuming Ohm's law. Region of transition from ordinary to superconductivity.

¶¶ V.p. He = pressure of saturated vapor of He at temperature of observation; unit = 1 mm of Hg:

V.p. He.....	765	480.2	461.9	456.1	394.4
$-t$.....	268.88	269.33	269.36	269.37	269.49
V.p. He.....	339.6	309.8	304.0	45	6
$-t$.....	269.61	269.67	269.69	270.74	271.5

*** Approximately minimum value.

††† Data from (93, 94) differ greatly from those of (21), and indicate R has a minimum near −80°C.

TABLE 2.—RESISTANCE OF PLATINUM BELOW −80°C (19, 75, 87, 88, 97, 157, 160)

I = Pt-23-1915 (19, 87, 97, 157, 160); II = Pt-23′-1915 (88, 160); III = Pt-29-P.T.R. (75); *see also* Fig. 8. R, R_0 = resistance (not resistivity) of the specimen at temperature t, °C, 0°C. t = centigrade temperature, °C; every t is negative.

$-t$	$100R/R_0$		
	I	II	III
80	68.158	68.017	67.782
82	67.350	67.205	66.964
84	66.542	66.393	66.146
86	65.733	65.581	65.328
88	64.923	64.769	64.508
90	64.113	63.955	63.688
92	63.303	63.141	62.866

TABLE 2.—(*Continued*)

$-t$	$100R/R_0$		
	I	II	III
94	62.492	62.325	62.044
96	61.680	61.509	61.222
98	60.867	60.692	60.400
100	60.053	59.874	59.576
102	59.237	59.055	58.752
104	58.421	58.235	57.926
106	57.605	57.415	57.100
108	56.788	56.593	56.274
110	55.970	55.771	55.446
112	55.150	54.949	54.618
114	54.329	54.125	53.788
116	53.507	53.301	52.958
118	52.685	52.476	52.127
120	51.863	51.650	51.295
122	51.039	50.823	50.463
124	50.215	49.995	49.629
126	49.391	49.167	48.795
128	48.567	48.337	47.959
130	47.741	47.507	47.123
132	46.915	46.675	46.286
134	46.087	45.842	45.448
136	45.257	45.008	44.609
138	44.427	44.173	43.769
140	43.595	43.337	42.928
142	42.761	42.500	42.086
144	41.927	41.661	41.244
146	41.092	40.821	40.401
148	40.255	39.979	39.555
150	39.418	39.135	38.709
152	38.580	38.291	37.861
154	37.740	37.446	37.013
156	36.899	36.600	36.164
158	36.057	35.752	35.314
160	35.213	34.904	34.463
162	34.367	34.054	33.609
164	33.519	33.204	32.755
166	32.670	32.353	31.901
168	31.820	31.501	31.045
170	30.970	30.647	30.189
172	30.120	29.793	29.331
174	29.268	28.937	28.471
176	28.416	28.079	27.611
178	27.563	27.219	26.749
180	26.709	26.356	25.885
182	25.855	25.491	25.020
184	25.001	24.625	24.154
186	24.146	23.758	23.285
188	23.292	22.893	22.416
190	22.438	22.030	21.551
192	21.584	21.169	20.689
194	20.730	20.311	19.830
196	19.876	19.455	18.974
198	19.024	18.601	18.120
200	18.176	17.750	17.268
201	17.754	17.326	
202	17.333	16.903	
203	16.913	16.481	
204	16.494	16.060	
205	16.076	15.640	
206	15.659	15.221	
207	15.244	14.804	
208	14.831	14.389	

TABLE 2.—(*Continued*)

−t	100R/R₀		
	I	II	III
209	14.419	13.975	
210	14.009	13.563	
211	13.601	13.153	
212	13.195	12.745	
213	12.791	12.339	
214	12.390	11.936	
215	11.993	11.536	
216	11.599	11.139	
217	11.208	10.745	
218	10.821	10.355	
219		9.969	
220		9.587	
221		9.209	
222		8.835	
223		8.466	
224		8.102	
225		7.743	
226		7.389	
227		7.040	
228		6.697	
229		6.360	
230		6.030	
231		5.708	
232		5.395	
233		5.092	
234		4.799	
235		4.516	
236		4.243	
237		3.980	
238		3.727	
239		3.484	

TABLE 2.—(*Continued*)

−t	100R/R₀		
	I	II	III
240		3.252	
241		3.031	
242		2.821	
243		2.623	
244		2.437	
245		2.263	
246		2.101	
247		1.952	
248		1.815	
249		1.688	
250		1.571	
251		1.464	
252	1.8422	1.3661	0.7902
253	1.7474	1.2773	0.7948
254	1.6630	1.1974	0.6320
255	1.5885	1.1263	0.5706
256	1.5227	1.0637	0.5198
257	1.4649	1.0095	0.4788
258	1.4147	0.9635	
259	1.3717	0.9255	
260	1.3355	0.8945	
261	1.306	0.8695	
262	1.2825	0.8495	
263	1.264	0.8335	
264	1.2495	0.8205	
265	1.239	0.810	
266	1.2325	0.8015	
267	1.2285	0.795	
268	1.226	0.7905	
269	1.2241	0.7879	
270	1.2225	0.7863	

TABLE 3.—EFFECT OF IMPURITIES, STRESS, HEAT TREATMENT, ETC., UPON RESISTANCE OF ELEMENTARY SUBSTANCES AT LOW TEMPERATURES

B = bar, section is circular unless another form is indicated, (c) = specimen was cast, (cd) = cold drawn, (cp) = cold pressed, (crl) = crystalline, Cryst = single crystal, (d) = distilled, (D) = drawn through diamond die, new diamonds, Diamag = diamagnetic, (dr) = drawn, Elec = electrolytic, (ex) = extruded while hot, (f) = filed, Fil = filament from incandescent electric lamp, F_V = fused *in vacuo*, FW = wire which has been flattened by hammering or by rolling, G = specimen was cast (c) or distilled (d) into a straight glass tube, Glo = specimen was annealed by glowing, (hd) = hard drawn, (H) = wire was drawn by Heraeus, *l* = length, M = malleable and ductile, P = plate, (p) = pressed, P.T.R. = Physikalisch-Technische Reichsanstalt, (r) = rolled, S = strip, Super = superconductive, (t) = turned or cut on lathe, tr. = trace, UG = same as G except that tube is U-shaped, Vac = resistance of specimen measured *in vacuo*, W = wire; □, □ = section is rectangular, is square; ⊥ = crystal is cut perpendicularly to the crystallographic (*c*) axis of trigonal symmetry. The dimension of the specimen (unit = 1 mm) is indicated by subscripts (if only one is given, the specimen is cylindrical, or is a thin narrow strip, and the subscript is its diameter, or the width of the strip); *e.g.*, $W_{0.5}$ = wire 0.5 mm in diameter, $B_{24,4,4.1}$ = bar 24 mm long, section 4 mm by 4.1 mm. In the column headed "Annealed," is given the annealing temperature, if known; "Yes" = annealed, "No" = not annealed. In the second column is given the date of publication or of measurement. Centigrade temperatures. Unit of length = 1 mm; of *p*, pressure, = 1 atm., of $\Delta R/pR$ = 1 (atm.)$^{-1}$; −182.95°, −252.76°, −268.88° = boiling point of O, H, He at 1 atm.

	Date	Source and designation	Impurities	Form and size	Annealed	100R/R₀ −182.95°	−192°	−252.76°	−268.88°	Lit.
Ag	1892	Pure Ag		W		30.3	26.9			(27)
	1904	Ag_{34}				27.9	24.3	3.74		(26)
	1907	Kahlbaum		$W_{0.5}$(dr)		30.0	26.8			(110)
	1907; 8	C. Hoitsema	0.18 %	$W_{0.1}$(H)		25.0*	21.1*	0.90*		(22, 133)
	1912	C. Hoitsema	0.18 % *ca.*	$P_{0.096}$		22.8	18.8	0.91		(3, 4, 124)
	1913	Heraeus, Ag_I	Chem. pure		Yes	25.39	21.4	1.47		(146, 147)
		Heraeus, Ag_{II}	Chem. pure		No	26.1	22.36	2.32		(146, 147)
	1919; 20	Heraeus		$W_{0.1}$	500°	24.6	20.71	0.54		(78, 79, 83)
Al	1892	Pure Al		W(hd)		28.3	24.6			(27)
	1893	Commercial Al	2.5 %	$W_{0.25}$		19.0	15.6			(28)
		Neuhausen Al	1 %	$W_{0.25}$		21.8	18.1			(28)
	1907	Kahlbaum		$W_{0.5}$(dr)		26.8	23.3			(110)
	1919	Al_{II}	1.6 %(Fe + Si)	$W_{0.2\text{ to }0.25}$	220°		17.80			(78)
					250°†		17.60			(78)
		Al_{III}	1.2 %(Fe + Si)	$W_{0.2\text{ to }0.25}$	220°		14.78			(78, 83)
					250°†		14.51			(78, 83)

TABLE 3.—(*Continued*)

	Date	Source and designation	Impurities	Form and size	Annealed	$100R/R_0$ −182.95°	−192°	−252.76°	−268.88°	Lit.
Al	1919; 20	Al_{IV}	0.4 %(Fe + Si)	$W_{0.2\ to\ 0.2i}$	225°		15.72			(78, 79, 83)
					250°†	18.9*	14.91*	4.27*		
					300°		15.64			
					500°		18.88			
					600°		21.61			
		Mylius, Al_V	0.1 %(Fe + Si)	$W_{0.2\ to\ 0.25}$	225°		17.56			(78, 79, 83)
					250°		17.53			
					250°†	21.4	17.39	5.94		
					300°		18.14			
					500°		20.40			
	1924; 26	Bureau of Standards	Fe = 0.18 %, Si = 0.15 %	$W_{0.5}$(cd)					6.77	(157, 160)
Au	1901	Roberts Austen, Au_{40}	Purest			29.2	25.5	3.29		(25)
	1904	Same as Au_{40}(?), Au_{33}				34.7	31.3	11.15		(26)
	1907	Kahlbaum		$W_{0.5}$(dr)		32.7	29.6			(110)
	1906; 8	C. Hoitsema, Au_0	0.03 %	$W_{0.1}$(H)		30.07	26.27	4.579		(22, 131, 133)
	1907; 08; 11	C. Hoitsema, Au_{III}	0.015 %	$W_{0.1}$(H)	Yes	27.65	23.88	1.627	1.020	(22, 116, 133)
	1907; 8	C. Hoitsema, Au_{IV}	0.005 %	$W_{0.1}$(H)	Yes	27.18	23.39	0.899		(22, 133)
		C. Hoitsema, Au_V	0.005 %	$W_{0.1}$(H)	Yes	27.10	23.30	0.835		(22, 133)
	1912	C. Hoitsema	<0.03 %	$P_{0.1}$		28.7	25.1	3.5		(3, 4, 124)
	1913	Heraeus, Au_I	Chem. pure	W	Glo	27.4	24.00	1.90		(146, 147)
		Heraeus, Au_{II}	Chem. pure	W	No	28.3	24.93	2.93		
		Handelsmetall Anst., Au_{III}	0.01 %, Elec	W	Glo	27.8	24.40	2.23		
		Handelsmetall Anst., Au_{IV}	0.01 %, Elec	W	No	28.7	25.31	3.43		
	1915	Mylius	0.001 %	Cast		27.1	23.2	0.69		(83, 102)
	1917	C. Hoitsema, Au-11-1915	Minting‡	$W_{0.1}$(D)	Glo§	27.08*	23.27*	0.825*	0.223*	(14, 17, 18)
		C. Hoitsema, Au-12-1915	Minting‡	$W_{0.05}$(D)	Glo§	27.20	23.40	0.891		(17, 18)
	1919; 20	(?)		$W_{0.1}$	500°	27.5	23.75	0.68		(78, 79, 83)
	1925	Mylius	0.001 %	$W_{0.25}$(dr)	No	28.03	24.3	1.9	1.073	(104)
		Mylius	0.001 %	$W_{0.25}$(dr)	350°		23.15	0.698	0.109	(104)
		Mylius, Au-1*a*	0.001 %	Cryst			23.03	0.674	0.093	(104)
		Mylius, Au-1*b*	0.001 %	Cryst			22.96	0.633	0.039	(104)
Bi	1897	Hartmann and Braun	Pure, Elec	$W_{0.5}$(p)		39.0	35.8			(33)
	1907; 8	Hartmann and Braun, No. 301		Spiral		41.35*	39.2*	22.43*		(22, 133)
	1913	Kahlbaum	0.07 % *ca.*	B_{25}(c)		37.7	33.8			(41)
	1919	Mylius and Groschuff	Pure	$W_{0.2}$(p)	200°	38.6	35.59			(78, 83)
Cd	1893	Matthey	Pure	$W_{0.7}$(dr)		29.5	25.8			(28)
	1912	Kahlbaum		B		30.3	26.8			(37)
	1913	Kahlbaum, Cd_I	<0.01 %	W(cd)		28.78	25.20	2.36		(146, 147)
		Kahlbaum, Cd_{II}	<0.01 %	W(ex)		28.66	25.09	2.21		(146, 147)
	1914	Kahlbaum	<0.01 %	G(c)		29.2	25.6	2.06	0.04	(137)
	1919; 20	Kahlbaum, Cd_2	<0.01 %	$W_{0.2}$	220°	29.0	25.34	2.14		(78, 79, 83)
	1924; 26	Kahlbaum, Cd-1920-I	<0.01 %	$W_{0.25}$(ex)		28.70*	25.15*	2.23*	0.143*	(157, 159, 160)
		Kahlbaum, Cd-1919-I		$W_{0.22}$(ex)		March, 1920	Change with time		0.327	(157, 160)
		Kahlbaum, Cd-1919-I		$W_{0.22}$(ex)		January, 1923			0.290	
Co	1921	Heraeus, Co_I		$W_{0.25}$	500°		16.10			(80)
		Kahlbaum, Co_{II}	(F_V in SiO_2)		500°		13.5*			(80)
Cs	1908	Hackspill's method		$UG_{0.5\ to\ 1}$(d)		29.3	26.3			(52, 53, 54)
	1910	Hackspill's method, tube 3		$G_{10\ to\ 20}$(d)		28.6*	25.9*			(57)
Cu	1885	Electrolytic conductivity = 98 %		Coil		21.3	17.5			(166)
	1901	Johnson and Matthey				19.6	15.8	0.95		(25)
	1907	Kahlbaum		$W_{0.5}$(dr)		20.8	18.4			(110)
	1912	Felten and Guillaume	Elec			16.3	12.3	1.04		(3, 4, 124)
	1913	Leppin and Masche	Diamag	W(cd)		19.9	16.16	1.78		(146, 147)
	1914; 21	Kahlbaum, Cu_I, Cu_{36}		W(H)				0.85		(65, 69)
		Siemens and Halske, Cu_{II}, Cu_{37}		W		18.87*	15.0*	0.63*		(65, 69)
	1915	Siemens and Halske, Cu_I	Elec Diamag	W not (dr)	No	18.4	14.4	0.25		(83, 102)
		Electrolytic, Cu_{II}	Elec	W(dr)	Glo	19.2	15.3	1.13		(83, 102)
		Felten and Guillaume	Elec	S(f)				1.35		(90)
		Felten and Guillaume	Elec	S(r)				2.42		(90)
		Felten and Guillaume	Elec	S(r)	Yes			1.095		(90)
	1916	Commercial Cu		B		20.1	16.4	2.00		(149)
	1919; 20	Siemens and Halske, Cu_2		$W_{0.1}$	380°†	18.7	14.75	0.63		(78, 79, 83)
		Siemens and Halske, Cu_1		$W_{0.1}$	500°	19.0	15.02			
	1913	Natural crystals, Cu-b						0.27	0.11	(123, 157, 160)
	1916	Lake Michigan, crystal		B(t)			13.3	0.12		(149)
	1924; 26	Natural crystals, Cu_{III}				18.16	14.40	0.153		(157, 159, 160)
Fe	1893	Armstrong's	Mg = 0.25 %, S = 0.01 %	$W_{0.27}$(cd)		22.3	19.7			(28)
		Hopkins and Williams	Very soft	$W_{0.23}$	Yes	13.5	10.2			(28)
	1901	(?), Fe_{33}				22.9	20.3	12.88		(25)
	1907	Kahlbaum		$W_{0.5}$(dr)		26.5	23.7			(110)
	1912	Kolswa (Sweden)	0.18 % (C, S, P, Si, Mn)			21.8	19.1	11.07		(4, 125)
	1913	Hartmann and Braun, Fe_I	Elec	W(dr)	Glo	13.8	10.54	2.80		(146, 147)
		Hartmann and Braun, Fe_{II}	Elec	W(dr)	No		11.09	3.30		

TABLE 3.—(*Continued*)

	Date	Source and designation	Impurities	Form and size	Annealed	$100R/R_0$ −182.95°	−192°	−252.76°	−268.88°	Lit.
Fe	1919	Electrolytic, Fe_{I2}	Elec, F_v	$W_{0.2}$	300°	13.2	9.98			(78, 83)
		Electrolytic, Fe_{I1}	Elec, F_v	$W_{0.2}$	500°	13.2	10.03			(78, 83)
	1919; 20	Kahlbaum, Fe_{II}	0.01 %	$W_{0.2}$(dr)	380°†	12.1*	8.78*	1.13*		(78, 79, 83)
Ge	1922	Dennis	<0.1 %	$B_{24,4,4.1}$		97.5*	101*			(8)
Hg	1914	(R_0 extrapolated for solid Hg)				28.5*	25.4*	4.90*	0.176*	(137)
In	1924	de Haën, In-1922-II	Chem. pure	$W_{0.17}$(ex)		28.70*	25.55*	5.72*	3.394*	(157, 158, 159)
		For effect of pressure, *see* Fig. 6								
Ir	1911	Heraeus		□FW		32.5	29.5			(13)
	1919	P.T.R., Ir_I		W_1	600°	26.3*	22.54*			(78, 83)
K	1901	Johnson and Matthey				26.6	22.6	2.86		(25)
	1908	Hackspill's method		$UG_{0.5\text{ to }1}$(d)		31.8	29.0			(52, 53, 54)
	1924	Merck, K-1916-III	F_v	UG(d)		27.19*	24.0*	2.70*	0.702*	(164, 165)
Li	1908	Purified	K and Na free	$UG_{0.5\text{ to }1}$(d)		17.3	13.8			(52, 54)
	1920	Kahlbaum		B		17.0*	13.4*	0.73*		(103)
Mg	1893	Matthey	Zn free	$W_{0.6}$		23.0*	19.3*			(28)
	1907	Carlo Elba		$W_{0.5}$(dr)		31.7	28.5			(110)
Mo	1919	D. Gasglühlicht Ges., Mo_{II}		$W_{0.25}$Vac	500°	22.9*	19.31*			(78, 83)
		(?), Mo_I	Impure	$W_{0.25}$Vac	500°	27.0	23.65			(78, 83)
Na	1908	Hackspill's method		$UG_{0.5\text{ to }1}$(d)		21.9	18.1			(52, 53, 54)
	1910	Hackspill's method, tube 3		$G_{10\text{ to }20}$(d)		22.7				(57)
	1924	Kahlbaum, Na-1916-IV	F_v	UG(d)		24.40*	20.8*	0.91*	0.381*	(164, 165)
		Kahlbaum, Na-1916-V	F_v	UG(d)				1.00	0.474	(164, 165)
Ni	1892; 93	Dr. Ludwig Mond		Spiral (t)		15.5	12.6			(27, 28)
	1900	Electrolytic	Elec	$W_{0.25}$(dr)	Yes	20.8*	17.8*			(40)
	1904	Johnson and Matthey, Ni_{41}				20.8*	17.8*	8.55		(26)
	1907	Kahlbaum		$W_{0.5}$(dr)		20.1	17.3			(110)
	1909	Hartmann and Braun, "Reinnickel"	1 %(Mn, Cu, Fe)	$W_{0.028}$		28.2	25.3			(10)
	1912	"Schwerte" Ni	Pure	$P_{0.053}$		33.3	30.8	20.46		(4, 125)
	1913	Hartmann and Braun		W		31.8	29.2	20.5		(146, 147)
	1919				500°†					(78)
	1921	Kahlbaum, ID	0.5 %	$W_{0.3}$(ex)	200°(?)		15.40			(80)
		Heraeus, IIIB	0.05 %	W(ex)	500°		10.39			(80)
		Heraeus, IIID	0.05 %	W(ex)	500°		10.1			(80)
Pb	1893	Matthey (1884)	Very pure	$W_{0.7}$(cp)		29.6	26.4			(28)
	1907	Kahlbaum		$W_{0.5}$(dr)		35.7	32.7			(110)
	1907; 8	(?)	0.015 %	S(t)		29.69	26.40	3.04		(22, 133)
	1912	(?)		$W_{0.2}$		31.6	28.2	6.1		(126)
	1913	Kahlbaum, Pb_I	<0.01 %	W(cd)		30.8	27.43	4.68		(146, 147)
		Kahlbaum, Pb_{III}	<0.01 %	W(ex)		31.0	27.64	4.61		(146, 147)
	1913; 14; 21	Nernst		$W_{0.5}$		30.5	27.3	4.37		(63, 65, 69)
		Kahlbaum	<0.01 %	$W_{0.5}$(dr)		29.6	26.35	3.10		(63, 65, 69, 83)
	1915; 25; 26	Kahlbaum	<0.01 %	B_3(t)		29.7	26.4	3.02	Super	(83, 102, 104, 105)
	1915	Kahlbaum	<0.01 %	S cut				2.96		(90)
		Kahlbaum	<0.01 %	S(r)				2.96		(90)
	1919; 20	Kahlbaum	<0.01 %		200°	29.6	26.34	3.05		(78, 79, 83)
	1924; 26	Kahlbaum, Pb-1919-I	<0.01 %	$W_{0.12}$(ex)		29.53*	26.19*	2.96*	Super*	(140, 157, 159, 160)
		$t = -183°$, $p = 49$, $10^5\Delta R/pR = -2.32$; $p = 100$, $10^5\Delta R/pR = -2.2$; $t = -252.8°$, $p = 49.7$ or $= 100$, $10^5\Delta R/pR = -1.7$ (126)								
Pd	1893	Matthey	Very pure	$W_{0.25}$		27.2	23.6			(28)
	1904	Johnson and Matthey, Pd_{46}				27.8	24.2	6.05		(26)
	1912	Heraeus		$P_{0.100}$‖	Yes			5.15		(4, 124)
	1919; 20	Heraeus, Pd_1		$W_{0.1}$Vac(?)	500°	22.9*	18.74*	0.93*		(78, 79, 83)
	1919	Heraeus, Pd_2		$W_{0.1}$ air	500°	23.7	19.70			(78, 83)
Pt	1892	(Pure soft)	Pure	W	Yes	33.3	29.7			(27)
	1893	Johnson and Matthey, P_1		$W_{0.26}$		30.5	26.9	5.90		(25, 28)
		Matthey		$W_{0.08}$		27.9				(28)
	1896	Heraeus		$W_{0.05}$		31.4	27.5			(84, 85)
	1901; 21	Cambridge Sci. Inst. Co., Pt_1		W		25.482	21.59	1.694		(65, 69, 76, 77)
	1903	Heraeus, I	Chem. pure	$W_{0.05}$	Glo	28.3	24.6			(6, 7)
		Heraeus, II	Chem. pure	$W_{0.1}$	Glo	25.5	21.6			(6, 7)
	1904; 7; 8	(?), Pt_M		$W_{0.1}$		25.936	22.113			(22, 98, 100, 132)
	1904	Johnson and Matthey, P_7				26.3	22.3	2.42		(26)
	1905	"Standard Pt"		W			20.90			(155)
	1906; 8; etc.	Heraeus, Pt_I'		$W_{0.1}$(dr)	Yes	25.178	21.287	1.418		(22, 86, 97, 128, 129, 130, 132, 136)
	1907; 8	Heraeus, Pt_{III}		$W_{0.1}$	Yes	25.068	21.205			(22, 132)
		Heraeus, $Pt_{IV\text{ or }V}$		$W_{0.1}$	Yes¶	25.012	21.161			(22, 132)
		Heraeus, Pt_d		$W_{0.05}$		27.288	23.599	4.062		(22, 132)
	1907	Kahlbaum		$W_{0.5}$(dr)		34.5	31.2			(110)
	1911	Heraeus, Pt_B		$W_{0.05}$**				1.72	1.19	(112)
	1913; 21; 24	Heraeus, Pt_{29}		$W_{0.05}$††		24.610*	20.689*	0.724*		(62, 63, 65, 69, 70, 72, 73, 74, 75)
		Heraeus, Pt_{30}		$W_{0.05}$††		24.617	20.695	0.737		(62, 63, 65, 67, 69, 72, 73, 74)
		Heraeus, Pt_{32}		$W_{0.05}$‡‡		24.629	20.689	0.743		(62, 63, 65, 69, 71, 72, 74, 83)
	1915	Heraeus		W_2	Glo	24.5	20.6	0.60		(102)

TABLE 3.—(*Continued*)

	Date	Source and designation	Impurities	Form and size	An-nealed	$100R/R_0$ −182.95°	−192°	−252.76°	−268.88°	Lit.
Pt		Heraeus, Pt_{35}		W					0.600$_5$	(150)
	1915	Heraeus, Pt-22-1915	Very pure	$W_{0.05}$(D)	Glo§	25.823		2.153		(19)
	1915; etc.	Heraeus, Pt-23-1915	Very pure	$W_{0.05}$(D)	Glo§	25.449*	21.584*	1.771*	1.224*	(19, 87, 97, 157, 160)
	1915	Heraeus, Pt-24-1915	Very pure	$W_{0.05}$(D)	Glo§	25.420		1.775		(19)
	1917	Heraeus, Pt-21-1915	Very pure	$W_{0.05}$(D)	Glo§	25.038	21.136	1.219		(17, 18, 97)
	1917	Heraeus, Pt-26-1915	Very pure	$W_{0.1}$(D)	Glo§	24.808	20.901	1.000		(17, 18)
	1919	Heraeus		W	800°†	24.5	20.60	0.60		(78, 79)
	1921	Heraeus, Pt_{33}		W	Yes§§	24.700	20.78	0.819		(65, 69)
		Heraeus, Pt_{34}		W	Yes§§	24.682	20.76	0.806$_5$		(65, 69)
		Heraeus, Pt_{35}		W	Yes§§	24.528	20.60	0.610		(65, 69)
	1922	(?)		$W_{0.25}$		24.90				(91)
	1923; 25; 26	Heraeus, Pt-23′-1915		$W_{0.05}$(D)	Glo§§	25.080*	21.169*	1.298*	0.788*	(88, 160)
	1923; 25	Heraeus, Pt-27′-1915		$W_{0.05}$(D)	Glo§§	25.176	21.262			(88)
		Heraeus, Pt-31-1920		$W_{0.05}$(dr)	Glo§§	25.662	21.788	1.906		(88)
		Heraeus, Pt-32-1920		$W_{0.05}$(dr)	Glo§§	25.670	21.797	1.920		(88)
		Heraeus, Pt-36-1922		$W_{0.05}$(dr)	Glo§§	25.463	21.577	1.639		(88)
	1924; 26	P.T.R.(?), Pt-C-1914		$W_{0.14}$		25.723		2.068	1.559	(157, 159, 160)
		P.T.R.(?), Pt-D-1914		$W_{0.14}$		25.563	21.697	1.873	1.372	(157, 159, 160)
Rb	1908	Hackspill's method		UG$_{0.5\text{ to }1}$(d)		28.1	25.6			(52, 53, 54)
	1910	Hackspill's method, tube 5		G$_{10\text{ to }20}$(d)		23.2*	21.2*			(57)
Rh	1911	Heraeus		FW□		16.4	11.6			(13)
	1919	P.T.R., Rh_I		W_1(r)	600°	20.1*	16.19*			(78, 83)
Sb	1913	Kahlbaum	0.05 % *ca.*	B_{25}(c)		27.3*	24.4*			(41)
	1914	Merck	Pure	Cryst ⊥‖‖		25.3*	22.5*			(55)
Si	1913	de Haën	Some H_4SiO_4; <0.01 % (Fe, C)	B		288*	304*			(93, 94)
Sn	1893	(?)	Pure	$W_{0.68}$(ex)		26.0	22.4			(28)
	1914	Kahlbaum	<0.01 %	S(t)		26.4	22.5	1.21	0.052	(137)
	1923	Kahlbaum, Sn-1922-III	<0.01 %	$W_{0.40}$(ex)		25.83	22.25	1.18	0.075	(159)
	1924; 26	Kahlbaum, Sn-1922-A	<0.01 %	$S_{0.05}$(FW)		25.39*	21.80*	1.15*	0.100*	(157, 159, 160)
		Kahlbaum, Sn-1922-I	<0.01 %	$W_{0.15}$(ex)		26.28	22.65	1.22	0.079	(157, 159, 160)
	1925	(?)				25.36	21.66	1.20	0.079	(104)
		For effect of stress, *see* Figs. 10, 11								
Ta	1919	Lamp filament		Fil	2200°	33.2*	29.78*			(78, 83)
Te	1908	Commercial, purified		B$_{5\text{ to }7}$, l = 20 to 30		61	59			(52, 54)
	1912	Merck, purest		$P_{1.88}$¶¶		59.1*	57.8*	60.4*		(4, 127)
Ti	1908	de Haën	tr. (Fe, Si)	B		164*	170*			(93, 94)
Tl	1893	Ramsay		$W_{0.7}$(cp)		27.7	24.5			(28)
	1922; 24	Kahlbaum, Tl-1916-VIII		$W_{0.2}$(ex)***		27.85	24.62	3.07	0.168	(139, 157, 159)
		Kahlbaum, Tl-1916-IX		$W_{0.5}$(ex)		27.76*	24.54*	2.99*	0.084*	(139, 157, 159)
W	1919	Siemens and Halske, W_I		$Fil_{0.1}$	2500°	19.4*	15.63*			(78, 83)
		Pintsch, W_{II}	Th	W(crl)		28.1	24.58			(78)
	1921	Pirani		W		19.42	15.64			(69)
Zn	1913	Kahlbaum	<0.01 %	W(ex)			21.48	1.56		(146, 147)
	1919; 20	Kahlbaum	<0.01 %	W	200°	25.8	22.00	1.05		(78, 79, 83)
	1924; 26	Kahlbaum, Zn-1921-I	<0.01 %	$W_{0.4}$(cd)	†††	25.96*	22.16*	1.37*	0.656*	(157, 159, 160)
Zr	1908	de Haën	tr. C	B		56o	76o			(93, 94)
	1924	Philips Lamp Works, Zr_2	0.1 %	□B$_{0.15,0.15}$	2400°	77.90	76.56			(20)
		Philips Lamp Works, Zr_4	0.1 %	□B$_{0.15,0.15}$	2400°	76.22	74.81			(20)
	1925	Philips Lamp Works, Zr_5	0.12 %W	S(FW)M	No	26.2*	22.9*			(21)
		Philips Lamp Works, Zr_6	0.03 %W	W(crl)M	1600°	26.9	23.6			(21)

* Given in Table 1 or 2. † Most favorable annealing temperature is near this. ‡ Pure minting Au. § Successively glowed and immersed in liquid air several times. ‖ Plate was not in contact with liquid H. ¶ Annealed, unwound, rewound but not reannealed. ** Wound on glass cylinder while hot. †† Wound on mica cross. ‡‡ Wire enclosed in sealed glass tube. §§ And immersed in liquid H. ‖‖ Crystal split parallel to base; current passes ⊥ to *c*-axis. ¶¶ Circular plate 1.88 mm thick, 10 mm diameter, cast in a steel mold. *** Specimen has a joint. ††† Heated: 150 to 200°C, and hammered.

BIBLIOGRAPHY ARRANGED BY ELEMENTS

Ag (3, 4, 15, 22, 23, 25–28, 78, 79, 83, 95, 109, 110, 124, 133–135, 146, 147); Al (15, 27, 28, 78, 79, 83, 95, 107, 110, 157, 160); Au (3, 4, 14, 17, 18, 22, 23, 25–28, 78, 79, 83, 89, 90, 99, 100, 102, 104, 105, 110, 113, 116, 119, 120, 124, 131, 133, 134, 137, 146, 147, 167); Bi (2, 4, 10, 11, 22, 23, 30, 31, 33, 39, 41, 78, 83, 124, 133–135); C (22, 27, 92, 111, 134, 135, 142, 145); Cd (28, 37, 47–49, 78, 79, 82, 83, 95, 137, 146, 147, 149, 157, 159, 160); Co (80, 146, 147); Cs (9, 52–54, 57); Cu (3, 4, 15, 25–28, 65, 69, 78, 79, 83, 90, 95, 101, 102, 110, 123, 124, 137, 146, 147, 149, 157, 159, 160, 166); Fe (4, 15, 25, 27, 28, 58, 78, 79, 83, 95, 110, 125, 137, 146, 147); Ga (157, 160); Ge (8, 157, 160); Hg (1, 15, 22, 23, 32, 42, 50, 51, 56, 113, 114, 115, 117, 125, 133, 134, 137, 152, 156, 167); In (157–159); Ir (13, 78, 83); K (9, 25, 52–54, 57, 164, 165); Li (9, 52, 54, 103, 138); Mg (15, 28, 110); Mo (78, 83); Na (9, 52–54, 57, 165); Ni (4, 10, 26, 27, 28, 40, 59, 78, 80, 83, 95, 110, 125, 135, 146, 147); Pb (22, 23, 28, 62, 63, 65, 69, 78, 79, 83, 90, 95, 102, 104, 105, 108, 110, 118, 121, 126, 133–135, 140, 146, 147, 149, 157, 159, 160); Pd (3, 4, 26, 28, 78, 79, 83, 124); Pt (6, 7, 15, 17–19, 22–29, 34, 35, 62–79, 83–88, 91, 97, 98, 100, 102, 106, 108, 110, 112, 116, 119, 120, 128–130, 132, 134–136, 146, 148, 150, 155, 157, 159–161, 167); Rb (9, 52–54, 57); Rh (13, 78, 83); Sb (37, 41, 55); Si (93, 94); Sn (14, 15, 27, 28, 56, 95, 104, 105, 118, 135, 137, 152, 153, 157, 159, 160); Ta (78, 83, 143, 144); Te (4, 52, 54, 127); Ti (93, 94); Tl (28, 139, 157, 159); W (69, 78, 83, 143); Zn (28, 47, 48, 49, 78, 79, 81, 83, 95, 105, 146, 147, 157, 159, 160); Zr (20, 21, 93, 94).

LITERATURE

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(1) Baltruszajtis, *165*, **1912A:** 888. (2) Beckman, *64P*, **15:** 649; 13. *168*, **No 130â**; 12. (3) Beckman, *64P*, **15:** 659; 13. *168*, **No. 130b**; 12. (4) Beckman, *168*, **Suppl. No. 40;** 15. (5) Benedicks, *200*, **13:** 351; 16. (6) Bestelmeyer, *Diss.*, München, 1903. (7) Bestelmeyer, *8*, **13:** 944; 04. (8) Bidwell, *2*, **19:** 447; 22. (9) Bidwell, *2*, **23:** 357; 24.

(10) Blake, *8*, **28:** 449; 09. (11) Borelius and Lindh, *8*, **51:** 607; 16. (12) Brillouin, *Conseil-Solvay de Physique*, p. 195. Paris, Gauthier-Villars, 1923. (13) Broniewski and Hackspill, *34*, **153:** 814; 11. (14) Burgers and Onnes, *0*. (15) Cailletet and Bouty, *34*, **100:** 1188; 85. (16) Cassel, *96*, **33:** 477; 25. (17) Cath, *Diss.*, Leiden, 1908. (18) Cath, Qnnes and Burgers, *64P*, **20:** 1163; 18. *168*, **No. 152c**; 17. (19) Cath, Onnes and Burgers, *0*.

(20) Clausing, *208*, **4:** 372; 24. (21) Clausing, *0*. (22) Clay, *Diss.*, Leiden, 1908. (23) Clay, *168*, **No. 107d**; 08. (24) Dewar, *5*, **64:** 227; 99. (25) Dewar, *5*, **68:** 360; 01. (26) Dewar, *5*, **73:** 244; 04. (27) Dewar and Fleming, *3*, **34:** 326; 92. (28) Dewar and Fleming, *3*, **36:** 271; 93. (29) Dewar and Fleming, *3*, **40:** 95; 95.

(30) Dewar and Fleming, *3*, **40:** 303; 95. (31) Dewar and Fleming, *5*, **60:** 72; 97. (32) Dewar and Fleming, *5*, **60:** 76; 97. (33) Dewar and Fleming, *5*, **60:** 425; 97. (34) Dickson, *3*, **44:** 445; 97. (35) Dickson, *3*, **45:** 525; 98.

(36) Epstein, *96*, **32:** 620; 25. (37) Eucken and Gehlhoff, *88*, **14:** 169; 12. (38) Feussner, *96*, **25:** 215; 24. (39) Fleming, *121*, **37:** 267; 96.
(40) Fleming, *5*, **66:** 50; 00. (41) Gehlhoff and Neumeier, *88*, **15:** 876; 13. (42) Gehlhoff and Neumeier, *88*, **21:** 201; 19. (43) Grüneisen, *88*, **15:** 186; 13. (44) Grüneisen, *63*, **19:** 382; 18. (45) Grüneisen, *88*, **20:** 36; 18. (46) Grüneisen, *88*, **20:** 53; 18. (47) Grüneisen and Goens, *243*, **44:** 83; 24. (48) Grüneisen and Goens, *96*, **26:** 250; 24. (49) Grüneisen and Goens, *243*, **46:** 104; 26.
(50) Grunmach, *8*, **35:** 764; 88. (51) Grunmach, *8*, **37:** 508; 89. (52) Guntz and Broniewski, *34*, **147:** 1474; 08. (53) Guntz and Broniewski, *34*, **148:** 204; 09. (54) Guntz and Broniewski, *42*, **7:** 464; 09. (55) de Haas, *64P*, **16:** 1110; 14. (56) de Haas, Sizoo and Onnes, *64P*, **29:** 250; 26. *168*, **No. 180d;** 26. (57) Hackspill, *34*, **151:** 305; 10. (58) Harrison, *58*, **66:** 343; 02. (59) Harrison, *3*, **3:** 177; 02.
(60) Hauer, *8*, **51:** 189; 16. (61) Hauer, *63*, **18:** 149; **17.** (62) Henning, *243*, **33:** 86; 13. (63) Henning, *8*, **40:** 635; 13. (64) Henning, *8*, **41:** 1064; 13. (65) Henning, *243*, **34:** 116; 14. (66) Henning, *8*, **43:** 282; 14. (67) Henning, *243*, **35:** 174; 15. (68) Henning, *B62*. (69) Henning, *96*, **5:** 264; 21.
(70) Henning, *243*, **42:** 129; 22. (71) Henning and Heuse, *243*, **44:** 106; 24. (72) Henning and Heuse, *96*, **23:** 95; 24. (73) Henning and Heuse, *96*, **23:** 105; 24. (74) Henning and Heuse, *243*, **45:** 198; 25. (75) Henning, *Handbuch der Physik*, **IX.** Berlin, Springer, 1926. (76) Holborn, *8*, **6:** 242; 01. (77) Holborn, *243*, **22:** 114; 02. (78) Holborn, *8*, **59:** 145; 19. (79) Holborn, *243*, **40:** 144; 20.
(80) Holborn, *96*, **8:** 58; 21. (81, 82) Holborn, quoted in (48). (83) Holborn, Scheel and Henning, *B63*. (84) Holborn and Wien, *8*, **59:** 213; 96. *76*, **1896:** 673. (85) Holborn and Wien, *243*, **17:** 142; 97. (86) Holst, *64P*, **18:** 829; 16. *168*, **No. 148a;** 15. (87) van der Horst, van Agt, Onnes and Tuyn, *0*. (88) van der Horst, Onnes and Tuyn, *0*. (89) Keesom and Onnes, *64P*, **17:** 894; 15. *168*, **No. 143;** 14.
(90) Keesom and Onnes, *64P*, **18:** 484; 16. *168*, **No. 147a;** 15. (91) Keyes, Townshend and Young, *285*, **1:** 243; 22. (92) Koenigsberger and Reichenheim, *63*, **7:** 570; 06. (93) Koenigsberger and Schilling, *63*, **9:** 347; 08. (94) Koenigsberger and Schilling, *8*, **32:** 179; 10. (95) Lees, *62*, **208:** 381; 08. (96) Lindemann, *76*, **1911:** 316. (97) Palacios-Martinez and Onnes, *18*, **6:** 31; 23. *168*, **No. 156b;** 23. (98) Meilink, *64P*, **7:** 290; 04. *168*, **No. 93;** 04. (99) Meilink, *64P*, **7:** 300; 05. *168*, **No. 93;** 04.
(100) Meilink, *Diss.*, Amsterdam, 1904. (101) Meissner, *88*, **16:** 262; 14. (102) Meissner, *8*, **47:** 1001; 15. (103) Meissner, *96*, **2:** 373; 20. (104) Meissner, *63*, **26:** 689; 25. (105) Meissner, *243*, **46:** 104; 26. (106) Nernst, *76*, **1911:** 306. (107) Nernst, *88*, **13:** 921; 11. (108) Nernst, *8*, **36:** 395; 11. (109) Niccolai, *22*, **16 I:** 757; 07. *63*, **9:** 367; 08.
(110) Niccolai, *22*, **16 I:** 906; 07. (111) Noyes, *2*, **24:** 190; 24. (112) Onnes, *64P*, **13:** 1093; 11. *168*, **No. 119;** 11. (113) Onnes, *64P*, **13:** 1274; 11. *168*, **No. 120b;** 11. (114) Onnes, *64P*, **14:** 113; 12. *168*, **No. 122b;** 11. (115) Onnes, *64P*, **14:** 818; 12. *168*, **No. 124c;** 11. (116) Onnes, *168*, **Suppl. No. 29;** 13. (117) Onnes, *64P*, **15:** 1406; 13. **16:** 113; 14. *168*, **Nos. 133a, 133b, 133c;** 13. (118) Onnes, *64P*, **16:** 673; 14. *168*, **No. 133d;** 13. (119) Onnes, *168*, **Suppl. No. 34b;** 13.
(120) Onnes, *168*, **Suppl. No. 35;** 13. (121) Onnes, *64P*, **17:** 12, 278, 514; 15. *168*, **Nos. 140b, 140c, 141b;** 14. (122) Onnes, *B60*, p. 175. *168*, **No. 50a;** 24. (123) Onnes, quoted in (160). (124) Onnes and Beckman, *64P*, **15:** 307; 13. *168*, **No. 129a;** 12. (125) Onnes and Beckman, *64P*, **15:** 981; 13. *168*, **No. 132a;** 12. (126) Onnes and Beckman, *64P*, **15:** 947; 13. *168*, **No. 132b;** 12. (127) Onnes and Beckman, *64P*, **15:** 997; 13. *168*, **No. 132d;** 12. (128) Onnes and Braak, *64P*, **11:** 333; 09. *168*, **No. 107a;** 08. (129) Onnes, Braak and Clay, *64P*, **10:** 422; 08. *168*, **No. 101a;** 07.
(130) Onnes and Clay, *64P*, **9:** 207; 07. *168*, **No. 95c;** 06. (131) Onnes and Clay, *64P*, **9:** 213; 07. *168*, **No. 95d;** 06. (132) Onnes and Clay, *64P*, **10:** 200; 08. *168*, **No. 99b;** 07. (133) Onnes and Clay, *64P*, **10:** 207; 08. *168*, **No. 99c;** 07. (134) Onnes and Clay, *64P*, **11:** 345; 09. *168*, **No. 107c;** 08. (135) Onnes and Hof, *64P*, **17:** 520; 15. *168*, **No. 142b;** 14. (136) Onnes and Holst, *64P*, **17:** 501; 15. *168*, **No. 141a;** 14. (137) Onnes and Holst, *64P*, **17:** 508; 15. *168*, **No. 142a;** 14. (138) Onnes and Sizoo, *0*. (139) Onnes and Tuyn, *64P*, **25:** 443; 22. *18*, **6:** 284; 23. *168*, **No. 160a;** 22.
(140) Onnes and Tuyn, *64P*, **25:** 451; 22. *18*, **6:** 293; 23. *168*, **No. 160b;** 22. (141) Onnes and Tuyn, *168*, **Suppl. No. 58;** 26. (142) Piesch, *75*, **102 IIa:** 768; 93. (143) Pirani, *88*, **12:** 301; 10. (144) Pirani and Meyer, *9*, **17:** 908; 11. (145) Roberts, *8*, **40:** 453; 13. (146) Schimank, *Diss.*, Berlin, 1914. (147) Schimank, *8*, **45:** 706; 14. **46:** 176; 15. (148) Schmitz, *5*, **72:** 177; 03. (149) Schott, *88*, **18:** 27; 16.
(150) Schultze, *243*, **35:** 176; 15. (151) Simon, *7*, **109:** 136; 24. (152) Sizoo, *Diss.*, Leiden, 1926. (153) Sizoo, de Haas and Onnes, *64V*, **35:** 617; 26. *168*, **No. 180c;** 26. (154) Sizoo and Onnes, *64P*, **28:** 656; 25. *168*, **No. 180b;** 25. (155) Travers and Gwyer, *5*, **74:** 528; 05. (156) Tsutsumi, *159*, **7:** 93; 18. (157) Tuyn, *Diss.*, Leiden, 1924. (158) Tuyn and Onnes, *64P*, **26:** 504; 23. *18*, **7:** 289; 24. *168*, **No. 167a;** 23. (159) Tuyn and Onnes, *0*.
(160) Tuyn and Onnes, *18*, **10:** 5; 26. *168*, **No. 181;** 26. (161) Van Dusen, *1*, **47:** 326; 25. (162) Vegard, *88*, **19:** 344; 17. (163) Wien, *76*, **1913:** 184. (164) Woltjer and Onnes, *0*. (165) Woltjer and Onnes, *B60*, p. 211. *168*, **No. 173a;** 24. (166) Wróblewski, *75*, **92 II:** 311; 85. *8*, **26:** 27; 85. (167) Zernike, *64V*, **23:** 742; 14.

ELECTRICAL RESISTIVITY OF PURE METALS AT TEMPERATURES ABOVE −80°C

FRANK WENNER

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TABLE 1.—ELECTRICAL RESISTIVITY (ρ) OF SINGLE CRYSTALS OF METALS BETWEEN 0 AND 100°C, AND THE EFFECT OF PRESSURE (13)

$\rho_t = \rho_{t'}[1 + \alpha(10)^{-3}(t - t')]$. If R_0 = resistance of a given crystal at 0°C and 1 atm., $\frac{1}{R_0}\cdot\frac{\partial R_0}{\partial P} = a(10)^{-6}$. ||, ⊥ indicate the direction of the current with reference to the crystallographic c-axis. t, t' = centigrade temperature, °C. Unit of $\rho = 10^{-6}$ ohm cm; of P = 1 kg/cm² = 14.22 lb./in.² = 0.968A_n.

TABLE 1.—(*Continued*)

	t'	$\rho_{t'}$	α	a		t'	$\rho_{t'}$	α	a
Bi‖	20	138	4.09	+24.5	Sb‖	20	35.6	5.32	+17.2
⊥	20	109	4.09	+ 7.5	⊥	20	42.6	4.64	+ 1.05
C*⊥	0	39 60.2	2.7		Sn‖	20	14.3	4.10	−10.96
					⊥	20	9.9	4.29	−10.28
Cd‖	20	8.30	3.94	−13.1	W	20	5.48		
⊥	20	6.80		− 8.7	Zn‖	20	6.13	3.87	−10.87
Cu*	20	1.5106			⊥	20	5.91	3.86	− 6.55
Mo*	0	5.03	4.73						

* Source of data: C, graphite (70); Cu (20); Mo (35).

Table 2.—Electrical Resistance of Pure Metals at Temperatures Above −80°C: Polycrystalline Metals

r_t for a liquid = resistivity (ρ_t) at temperature, t.

r_t for a solid = resistance at temperature, t, of a specimen which at room temperature (t_R) has a length (in direction of current) = 1 cm, and a uniform transverse sectional area = 1 cm². If the coefficient of linear thermal expansion is a, $\rho_t = r_t[1 + a(t - t_R)]$, the unit of ρ being 1 ohm cm if the unit of r is 1 ohm; r_t is frequently called the resistivity; it would be better to call it the apparent resistivity.

$r_t = r_t[1 + \alpha(t - t')(10)^{-3} + \beta(t - t')^2(10)^{-6}]$ if $t_1 \leq t \leq t_2$

(A) = aged = seasoned; (an) = annealed, (av) = average, or mean value, com = commercial, cp = "chemically pure," (dr) = drawn, elec = electrolytic, fil = filament of incandescent electric lamp, graph = graphite, (hd) = hard drawn, IACS = International Annealed Copper Standard, Kb = material obtained from Kahlbaum, l = liquid, MS = Matthiessen standard, p = pure, pp = very pure, R = room temperature, s = solid, w = wire.

Example: What is the apparent resistivity of annealed commercial conductivity copper at 700°C? From the table we find $r_{t'} = 1.72$, $t' = 20$, $\alpha = 4.1$, $\beta = 0.43$; hence at 20° the resistivity is 1.72×10^{-6} ohm cm, and at 700°C $r_{700} = 1.72[1 + 0.0041 \times (700 - 20) + 0.000\,000\,43(700 - 20)^2] \times 10^{-6} = 6.86 \times 10^{-6}$ ohm cm.

Centigrade temperatures, °C. Unit of $r_{t'} = 10^{-6}$ ohm.

	t'	$r_{t'}$	α	β	t_1	t_2	Remarks	Lit.
Ag	20	1.622	3.61		−80	400	p	(61)
	960.5	8.4*s*						(67)
	1000	17.01*l*	0.69		960.5	1340		(67)
Al	0	2.62	4.46	1.8	−80	400	Kb	(61)
	20	2.820					com(hd)	(26)
	20	2.67					(an)*w*pp	(26, 79)
	20		4.21		15	30	(hd)*w*pp	(79)
	657	20.13*l*	0.51		657	1100		(64)
As	20	35	Sublimed					(57)
Au	0	2.19	3.65		−80	1000	p	(23, 61, 66)
	1063	30.82*l*	0.46		1063	1500	p	(66)
Be	20	10.1						(80)
Bi	0	106.5	3.91	5.8	−80	250	elec	(24, 68)
	269	267*s*						(64, 68)
	269	127.5*l*	0.428		269	750		(68)
C	0	4100	−0.536		−80	100	fil (av)	(22)
	25	4600					*	(40)
	0	1375	−0.287		0	1400	graph†	(40)
	1400	825	+0.174		1400	2200	graph†	(40)
Ca	0	4.27*s*	3.642		0	600	99.57 %	(76)
Cd	0	6.83	3.733	3.69	−80	300	(av)	(55, 68, 69, 77)
	20	7.143					pp	(80)
	321	33.77*l*	−0.0802	0.679	321	700		(68)
Co	0	5.595	5.51	5.3	0	100	99.91 %	(28)
Cr	0	2.6	Powdered					(72)
Cs	0	18.83*s*	4.78		−80	25	(av)	(37, 38)
	28	36.4*l*	3.5		28	60	(av)	(37, 38)
Cu	20	1.78	3.8		−30	100	(hd)com	(21, 81)
	20	1.72	4.1	0.43	−80	1000	(an)com	(23, 65)
	20	1.7241	3.93				IACS	(44)
	20	1.7213					MS	(21, 81)
	20	1.6925	4.0				elec	(21, 81)
	1083	10.2*s*						(65)
	1083	21.3*l*	0.265		1083	1400		(65)
Fe	0	8.53	7.257	9.63	0	600	Kb	(58)
	20	9.78					99.983 %	(80)
Ga	0	53.4*s*	3.46		0	20		(37)
	30	27.2*l*	2.76		30	50		(37)
Ge	0	89×10^3	‡	‡	−80	100		(5)
Hg	−50	21.30*s*	5.84		−80	−50		(25)
	0	94.077*l*	0.9098	0.811	−30	300		(6, 25, 47)
	0	94.0766*l*	0.8862	1.1057	0	30	(av)	(36, 45, 49, 74)
In	0	8.37	4.77		−10	100		(29)
Ir	0	6.08	3.67		−80	100		(17)

Table 2.—(*Continued*)

	t'	$r_{t'}$	α	β	t_1	t_2	Remarks	Lit.
K	0	6.15*s*	5.814	15.3	−80	60		(38, 64)
	62.5	13.0*l*	4.92		62.5	350		(6, 60)
Li	0	8.55	4.747	1.03	−80	100		(37)
Mg	0	4.27	3.88	0.74	−80	400		(61)
	20	4.461						(27)
Mn	R	82					cp	(50)
Mo	0	5.14	4.791	0.346	0	2622	pp§	(82)
	0	5.14	4.62		0	200		(82)
Na	0	4.2*s*	5.087	6.10	−80	90		(38, 63)
Ni	0	6.93	5.44	6.0	−80	100	elec	(33)
	20	7.236					(an)pp	(80)
	450	28.90	0.827		450	1000	elec	(42)
	1451	108.0*l*	0.163		1451	1650		(6)
Pb	0	19.8	3.955	2.65	−80	300	(av)	
	20	20.63					p	(78)
	327	94.75*l*	0.482		327	1000		(60, 68)
Pd	0	10.00	3.610		−80	200	(av)	(2, 23, 46)
Pt	0	11.19	3.52	−0.55	−80	400		(61)
	0	9.83	3.981	−0.585	−80	1000	p‖	(59, 80)
Rb	0	11.3*s*	5.53		−80	35	(av)	(38, 51)
	50	23.15*l*	3.73		50	100		(51)
Rh	0	4.70	4.235	−1.85	−80	100		(17)
Ru	18	1o	(Only 1 significant figure)					(4)
Sb	0	39.0	4.144	6.2	−80	20	¶	(29)
Sn	0	10.48*s*	4.359	2.4	−80	230	(dr)	(46, 68)
	232	47.4*l*	0.565		232	1000	(av)	(6, 60, 68)
Sr	20	22.76					elec	(56)
Th	20	18.62						(80)
Ti	0	37o	−3.52	14.9	−80	250	Ti − α**	(48)
	500	67o	+3.38	8.0	430	580	Ti − β**	(48)
	650	60o	−0.89	2.2	580	780	Ti − γ**	(48)
Tl	0	17.65	4.051		−80	100		(23)
U	18	6o		(U + $x U_2C_3$)				(4)
W	0	5.00	5.238	0.7††	−80	3300	fil(A)	(34, 53, 83)
Zn	0	5.64*s*	3.468	1.16	−80	400		(3, 55)
	20	5.916*s*					(an)pp	(80)
	418	37.39*l*	−0.2785	0.40	418	850		(68)
Zr	0	164	1.16	−0.631	−80	30	99.9 %	(19)

* Furnace electrodes.

† Acheson graphite furnace electrodes.

‡ $r_t = Ae^B$; for Ge, $A = 17\,766$, $B = \dfrac{99.5438}{t + 273} + 0.004567(t + 273)$.

§ Seasoned wire.

‖ In the Callendar equation (Vol. 1, p. 54), $t - 100\left(\dfrac{R - R_0}{R_{100} - R_0}\right) = \delta\left[\left(\dfrac{t}{100} - 1\right)\dfrac{t}{100}\right]$, $\delta = 1.49$.

¶ Cast Sb. Above R, behavior is erratic; results discordant (6, 68).

** Only two significant figures; for Ti-α, only one significant figure if $t \neq 0$.

†† $r_t = r_0\{1 + \alpha t(10)^{-3} + \beta t^2(10)^{-6} + \gamma t^3(10)^{-9}\}$; $\gamma = 0.062$.

Table 3.—Effect of Hydrostatic Pressure upon Electrical Resistance of Metals between 0 and 100°C

For single crystals, *see* Table 1

Pressure range is 0 to 12 000 kg/cm² unless another is stated. R_0, R_p = resistance of the specimen at temperature, t, under pressure = 1 atm. (essentially 0), and = P, respectively. $R_p = R_0(1 + a(10)^{-6}P + b(10)^{-n}P^2$. Literature references are enclosed in ( ), are usually in the first column, and, in general, each refers to all the data given for the metal indicated.

Example: A bar of Bi at 25°C and 1 atm. has a resistance of 0.01173 ohm; a = 16.30, b = 4.17, $n = 10$, hence at $P = 8000$ kg/cm² and 25°C, this same bar would have a resistance of $R_{8000} = 0.01173[1 + 16.3(8000)(10)^{-6} + 4.17(8000)^2(10)^{-10}] = 0.01173(1 + 0.1304 + 0.0267) = 0.01357$ ohm. t = centigrade temperature, °C. Unit of $P = 1$ kg/cm² = 14.22 lb./in.² = 0.968 atm.

TABLE 3.—(*Continued*)

t	a	b	n
	Ag* (7)		
0	− 3.625	2.44	11
25	− 3.663	2.67	11
50	− 3.684	2.76	11
75	− 3.681	2.69	11
100	− 3.664	2.51	11
	Al* (10)		
0	− 4.50	3.08	11
25	− 4.45	2.64	11
50	− 4.42	2.36	11
75	− 4.43	2.86	11
100	− 4.41	3.50	11
	As (8)		
(?)	− 3.26		
	Au* (7)		
0	− 3.064	1.60	11
25	− 3.100	1.80	11
50	− 3.112	1.81	11
75	− 3.120	1.78	11
100	− 3.115	1.64	11
	Bi (7)		
0	+16.50	4.81	10
25	+16.30	4.17	10
50	+15.92	4.03	10
75	+15.67	3.75	10
	(8)†		
275*l*	−12.9‡	2.8‡	10
	C* (8)		
0	+ 7.51	−2.96	10
50	+ 4.01	−2.25	10
	Ca* (8)		
0	+10.28	2.19	10
25	+10.17	1.94	10
50	+ 9.92	1.80	10
75	+ 9.33	1.94	10
100	+ 9.25	1.80	10
	Cd* (7)		
0	−10.83	1.57	10
25	−11.12	1.68	10
50	−11.34	1.78	10
75	−11.51	1.88	10
100	−11.65	1.96	10
	Co* (10)		
30	− 0.934		
	Cs; *see* Fig. 1		
	Cu* (7)		
0	− 1.972	1.17	11
25	− 1.945	1.11	11
50	− 1.916	1.00	11
75	− 1.899	0.97	11
100	− 1.872	0.86	11
	Fe* (7)		
0	− 2.405	1.19	11
25	− 2.440	1.29	11
50	− 2.473	1.37	11
75	− 2.505	1.46	11
100	− 2.540	1.56	11
	Ga*† (8)		
30*l*	− 6.80	4.0	11
65*l*	− 6.10	6.0	11
100*l*	− 5.78	2.8	11

t	a	b	n
	Hg† (8)		
0*s*	−23.3§	1.97§	10
0*l*	−31.92‡	1.038‡	9
25	−31.60	0.840	9
50	−32.00	0.840	9
75	−32.75	0.850	9
100	−34.30	0.960	9
	In (7)		
0	−12.11	1.58	10
25	−12.84	1.94	10
50	−13.54	2.28	10
	Ir (11)		
30	− 1.74		
	K		
$R_p = R_0\left[\frac{6115 - 0.107P}{6115 + P}\right]$			
	at 0°C (14)		
	Li* (8)		
0 to 100	+ 7.72		
	Mg (8)		
0	− 4.080		
50	− 4.065		
100	− 4.018		
	Mo* (7)		
0	− 1.327	3.45	12
25	− 1.324	3.56	12
50	− 1.319	3.67	12
75	− 1.315	3.78	12
100	− 1.312	3.89	12
	Na (8)		
20*s*	−51.5	1.78	9
60*s*	−61.7	2.15	9
100*s*	−65.0‖	2.6‖	9
	Ni (10)		
0	− 1.880	4.14	12
25	− 1.909	5.5	12
50	− 1.934	6.89	12
75	− 1.957	8.25	12
100	− 1.975	9.64	12
	Pb* (7)		
0	−14.32	1.83	10
25	−14.72	2.08	10
50	−15.11	2.33	10
75	−15.52	2.57	10
100	−15.92	2.82	10
	Pd (7)		
0	− 1.965	5.8	12
25	− 1.967	6.7	12
50	− 1.959	6.7	12
75	− 1.941	5.8	12
100	− 1.916	4.4	12
	Pt (7)		
0	− 1.975	8.75	12
25	− 1.962	8.33	12
50	− 1.949	7.86	12
75	− 1.936	7.92	12
100	− 1.923	7.09	12
	Rb		
$R_p = R_0\left[\frac{4431 + 0.1154P}{4431 + P}\right]$			
	at 0°C (14)		

TABLE—3. (*Continued*)

t	a	b	n
	Rb.—(*Continued*)		
$R_p = R_0\left[\frac{3525 + 0.1168P}{3525 + P}\right]$			
	at 35°C (14)		
	Rh (11)		
30	− 1.74		
	Sb* (7)		
0	+12.20		
25	+11.07		
50	+ 9.94		
75	+ 8.81		
100	+ 7.68		
	Sn* (7)		
0	−10.40	1.00	10
25	−10.66	1.15	10
50	−10.92	1.30	10
75	−11.18	1.46	10
100	−11.44	1.61	10
	Sr (8)		
0	+48.93	1.59	9
50	+42.92	1.54	9
100	+39.17	1.55	9
	Tl (7)		
0	−13.44	1.61	10
25	−13.99	1.95	10
50	−14.57	2.29	10
75	−15.18	2.63	10
100	−15.81	2.96	10
	U (10)		
30	− 4.36		
	W* (8)		
0	− 1.346		
50	− 1.340		
100	− 1.368		

t	a	b	n
	Zn* (7)		
0	− 5.40	5.8	11
25	− 5.404	6.42	11
50	− 5.430	7.00	11
75	− 5.472	7.58	11
100	− 5.524	8.17	11
	Zr* (8)		
0	− 0.5		
0	− 0.398		
95	− 0.396		

* Purity as follows Ag = 99.97 %. Al = 99.976 % + 0.014 % Si + 0.007 % Fe + 0.003 % Cu. Au = 99.97 %. C, for 0° = Acheson graphite; for 50° = purified Acheson graphite. Ca = 99.9 + %. Cd is Kahlbaum's "K." Co = 99.73 % + 0.14 % Fe + 0.019 % S + 0.02 % Si + 0.09 % C + 0.00 % Ni. Cu = 99.995 + %. Fe = 99.97 %. Ga = 99.99 + % + tr. Zn. Li contains 0.7 % Al + tr. Fe. Mo = 99.8 %. Pb = 99.999 + % + tr. Cu, Ag. Sb = 99.45 % + tr. As, Fe, no other metals. Sn is Kahlbaum's "K." W = 99.97 %. Zn is Kahlbaum's "K;" tr. Cd, Fe, Pb. Zr for first line contains 1.8 % W; for other two 0.6 % W.

† Data for Ga, Hg, and liquid Bi have been corrected for compression of specimen, and the recorded coefficients refer to the *resistivity* of the material, not to the resistance of the specimen.

‡ For $P = 7000$.

§ For $7640 \gtrsim P \gtrsim 12\,000$; $\rho_p = \rho_{7640}\,[1 + a(10^{-6}(P - 7640) + b(10^{-n}(P - 7640)^2]$.

‖ For $1000 \gtrsim P \gtrsim 12\,000$; $R_p = R_{1000}\,[1 + a(10)^{-6}(P - 1000) + b(10)^{-n}(P - 1000)^2]$.

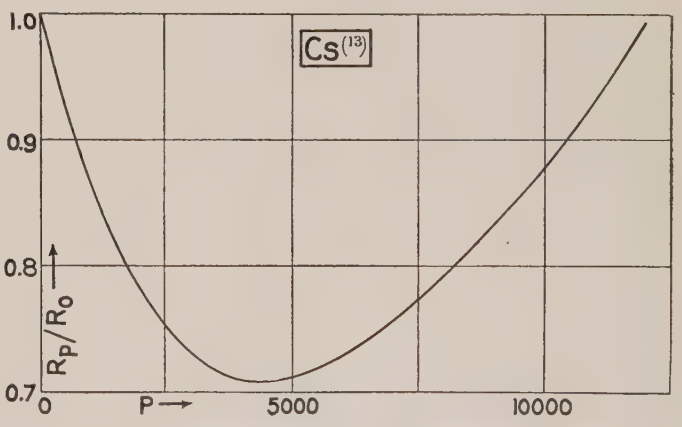


FIG. 1.—Effect of pressure upon electrical resistance of cesium (13).
Unit of P = 1 kg/cm² = 14.223 lb./in.² = 0.9678 atmosphere.

TABLE 4.—EFFECT OF TENSION UPON ELECTRICAL RESISTANCE OF PURE METALS (9, 12, 14)

R_0, R_s = resistance of a given specimen when tension = 0, = S, respectively. ρ_0, ρ_s = resistivity of a given material when tension = 0, = S, respectively. Temperature is the same for R_0, ρ_0 as for R_s, ρ_s. $a(10)^{-6} = (R_s - R_0)/R_0S'$; $\alpha(10)^{-6} = (\rho_s - \rho_0)/\rho_0S'$; S' = value of S which corresponds to tabulated values of a and α;

if all values of S from 0 to S' lead to same values for a and α, a † is placed after the value of S'; in this case $R_s = R_0(1 + a(10)^{-6}S)$, $\rho_s = \rho_0(1 + \alpha(10)^{-6}S)$ if $S \leq S'$. Unit of $S' = 1\ kg/cm^2 = 14.22$ lb./in.^{2}

I. Longitudinal effect, stress parallel to current

	a	α	S'
Ag	5.04	2.86	250†
Al*	6.3	4.0	130†
Au	6.17	3.87	120†
Bi*	−29.2	− 3.65	0.300†
Ca*	8.37	0.8	240†
Co*	0.994	0.19	0.100†
Cu*	2.66	1.3	580
	3.03	1.7	1080
Fe*	2.51	1.80	1025
	2.53	1.82	2050
Li	4.8	11	0.035†
Ni*	− 2.53	− 3.3	1900
Pd	3.19	1.66	457
	3.05	1.52	770
Pt*	2.82	1.78	400†
Sb	5.0	3.0	0.140†
Sr*	− 8.3	−21.2	400†

II. Transverse effect, stress perpendicular to current, $S' = 400$

	Purity	α
Pd	99.9%	0.51
Pt	99.9+%	0.34

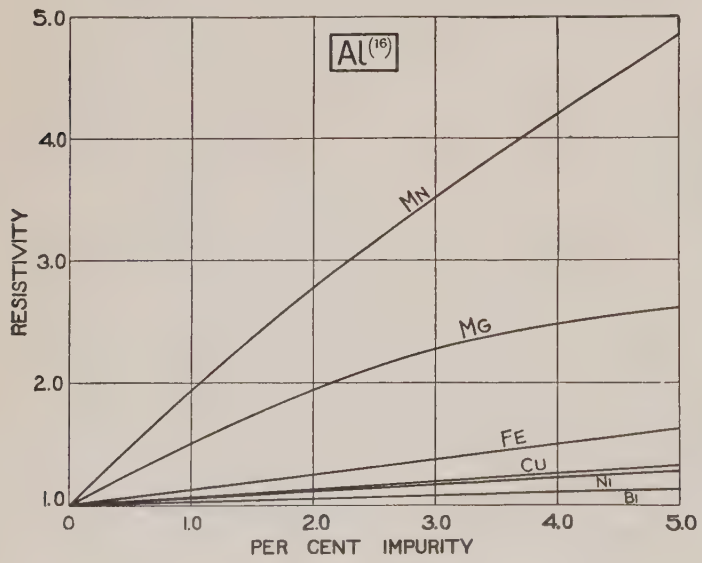
* Purity as follows: Al > 99.97 %; Au > 99.9 %; Bi = 99.97 % + 0.03 % Ag; Ca = chemically pure; Co = 98.71 % + 1.15 % Fe, 0.14 % Si, 0.012 % S, 0.039 % C; Cu > 99.995 %; Fe > 99.97 %; Ni > 99 %; Pt > 99.9 %; Sr > 98 %.

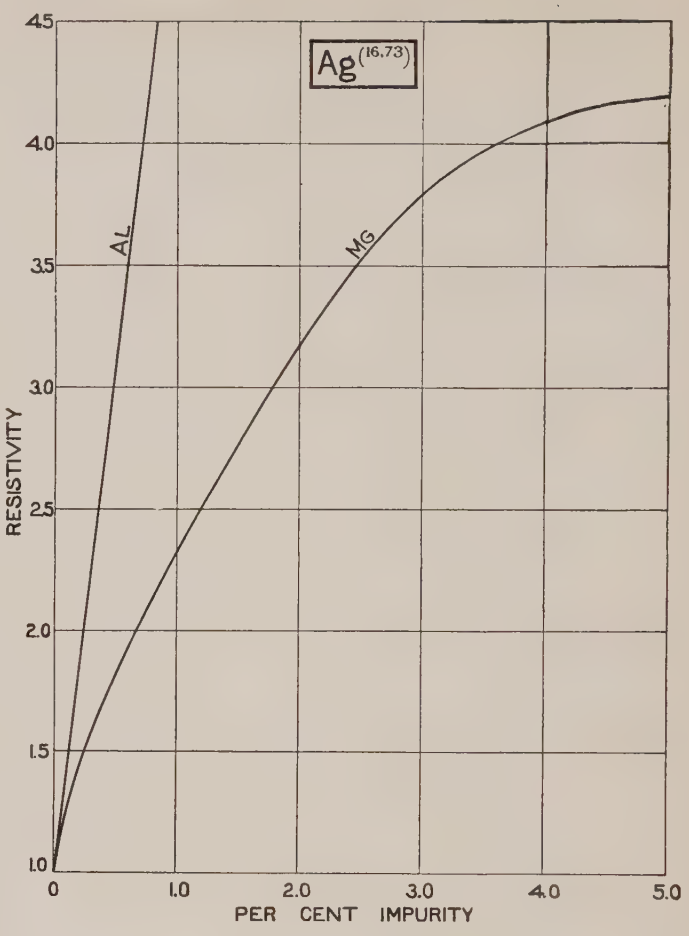
† Values of a and α are independent of S if $S \leq S'$; for Li, if $0.015 \leq S \leq S'$.

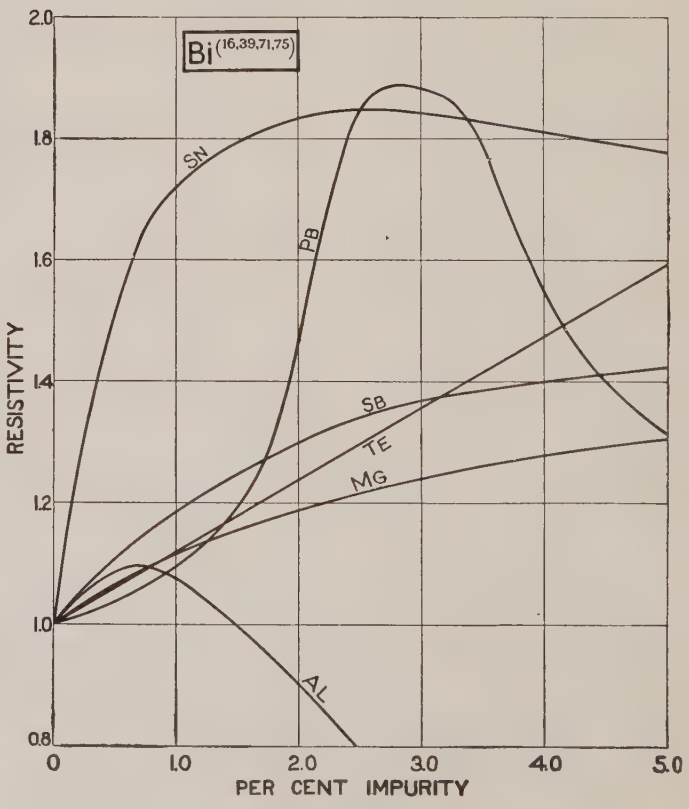
EFFECT OF IMPURITIES UPON THE ELECTRICAL RESISTIVITY OF METALS

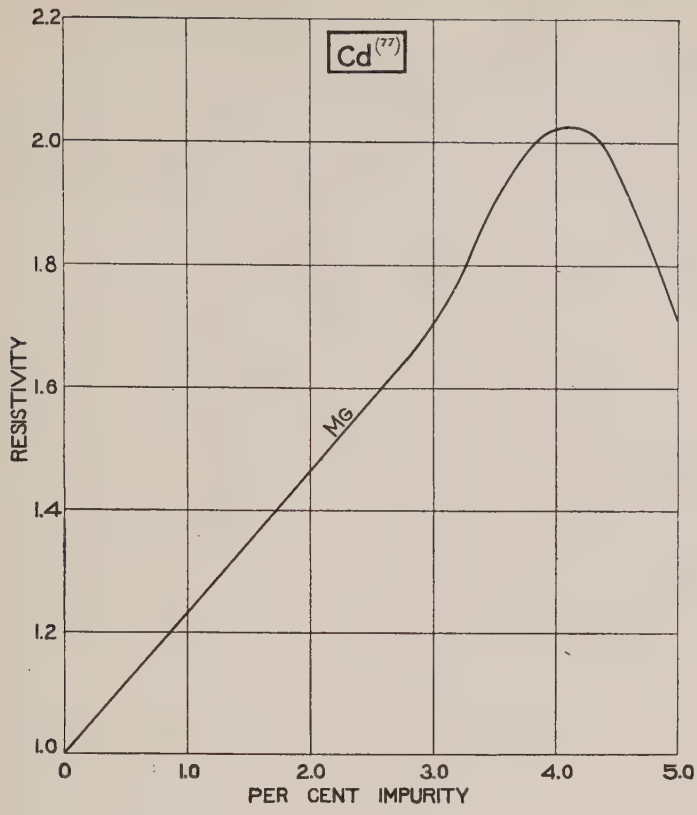
In each of the following figures each curve represents the variation of the resistivity of the metal named at the top of the figure with the amount of the impurity named upon the curve. The abscissae denote the per cent by weight of the impurity and the ordinates denote the values of ρ_i/ρ_0 at room temperature; ρ_i, ρ_0 = the resistivity of the impure, of the pure material, respectively. Numbers in ( ) are literature references.

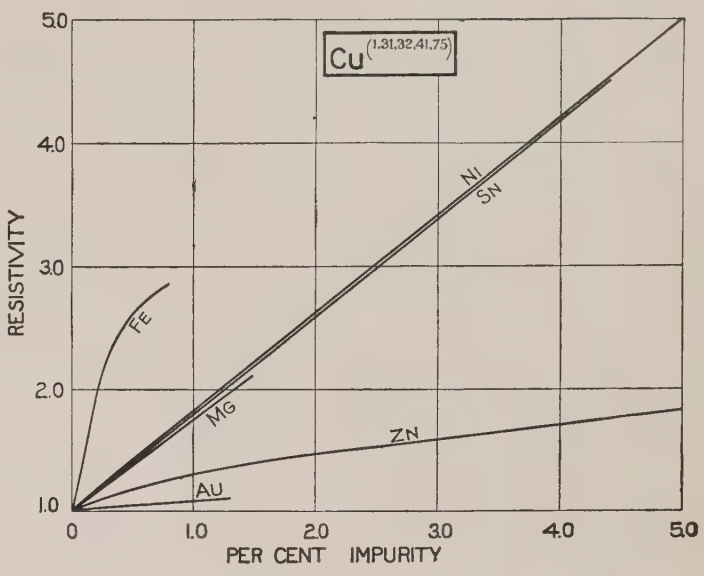
Example: From the curve showing the effect of Co upon the resistance of Cu, it is seen that the addition of 2.0% of Co corresponds to a relative resistivity (ρ_i/ρ_0) of 5.0; that is the resistivity (ρ_i) of this impure Cu is 5.0 times as great as that (ρ_0) of pure Cu.

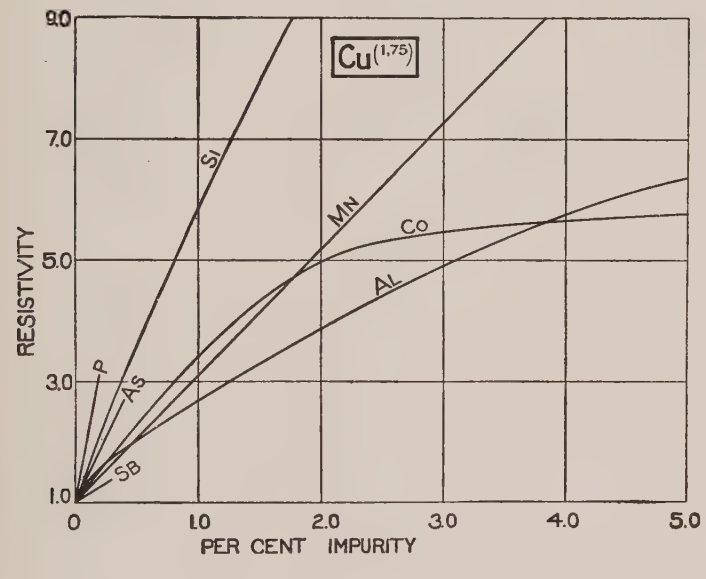


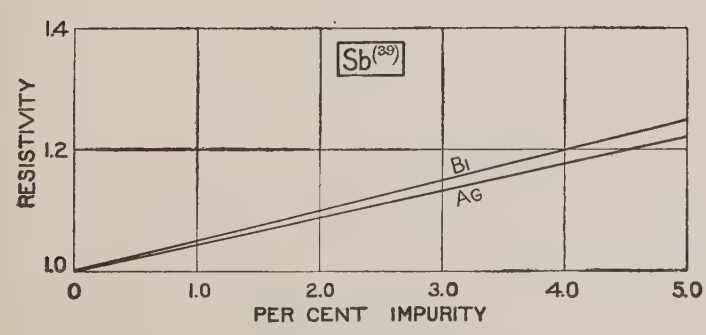


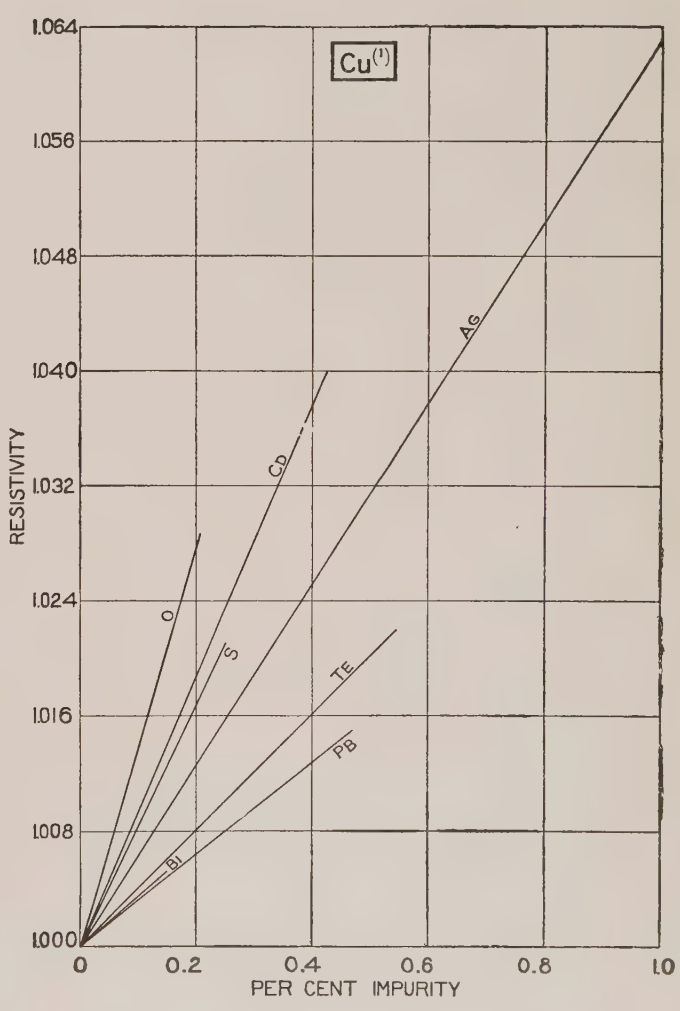


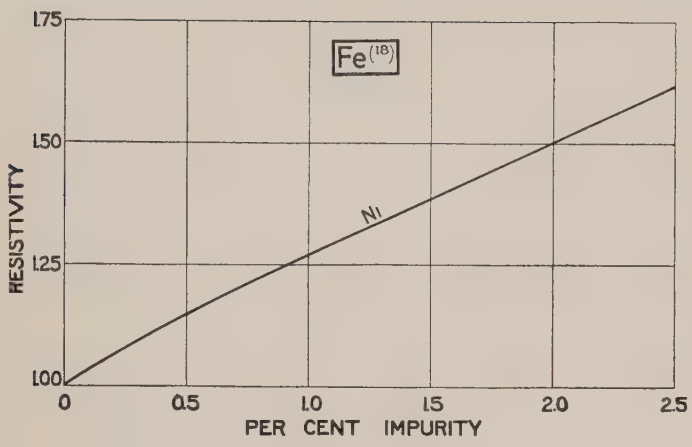

Cd(77)
RESISTIVITY
PER CENT IMPURITY
MG
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
1.0
2.0
3.0
4.0
5.0

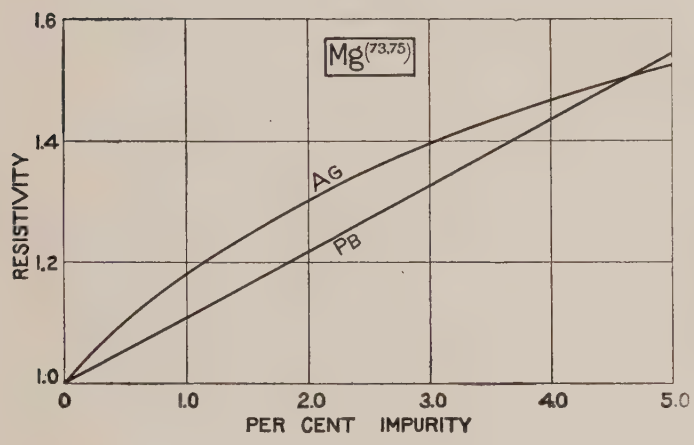

Cu(1,31,32,41,75)
RESISTIVITY
PER CENT IMPURITY
NI
SN
FE
MG
ZN
AU
5.0
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0

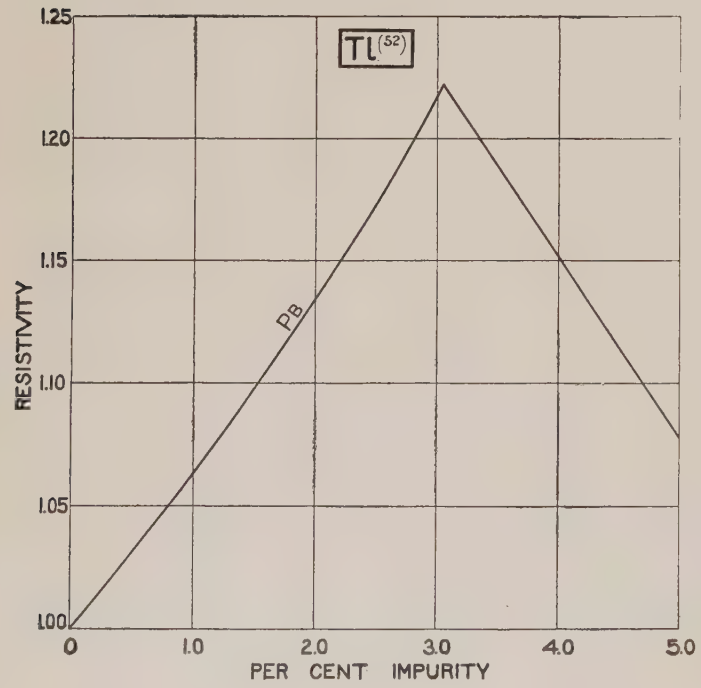

Cu(1,75)
RESISTIVITY
PER CENT IMPURITY
SI
MN
CO
AL
P
AS
SB
9.0
7.0
5.0
3.0
1.0
0
1.0
2.0
3.0
4.0
5.0

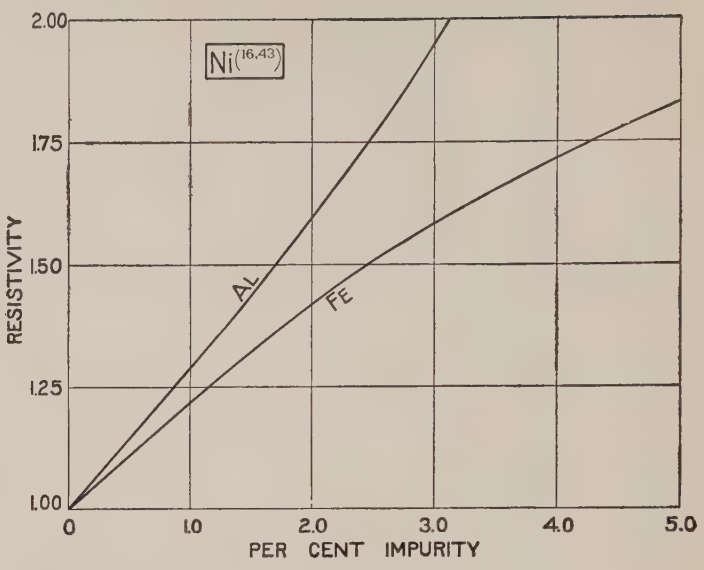

Sb(39)
RESISTIVITY
PER CENT IMPURITY
BI
AG
1.4
1.2
1.0
0
1.0
2.0
3.0
4.0
5.0

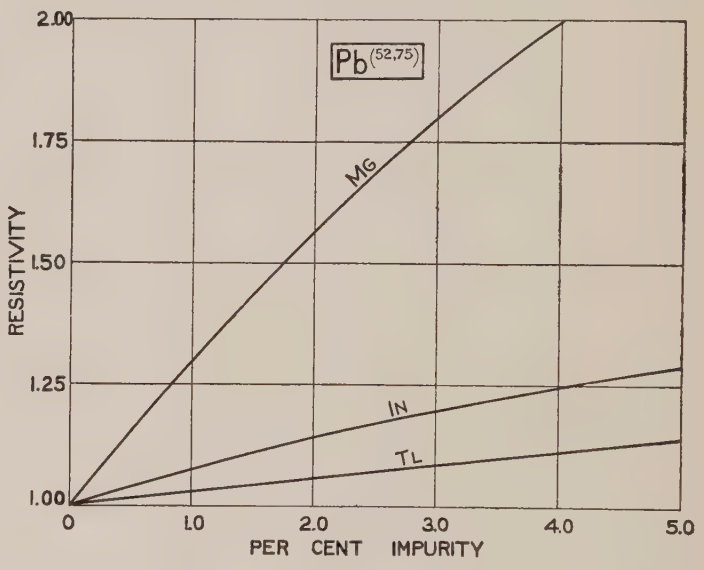

Cu(1)
RESISTIVITY
PER CENT IMPURITY
AG
CD
O
S
TE
PB
BI
1.064
1.056
1.048
1.040
1.032
1.024
1.016
1.008
1.000
0
0.2
0.4
0.6
0.8
1.0


Fe(18)
Ni
RESISTIVITY
1.75
1.50
1.25
1.00
0
0.5
1.0
1.5
2.0
2.5
PER CENT IMPURITY


Mg(73,75)
AG
PB
RESISTIVITY
1.6
1.4
1.2
1.0
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY


Tl(52)
PB
RESISTIVITY
1.25
1.20
1.15
1.10
1.05
1.00
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY


Ni(16,43)
AL
FE
RESISTIVITY
2.00
1.75
1.50
1.25
1.00
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY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MG
IN
TL
RESISTIVITY
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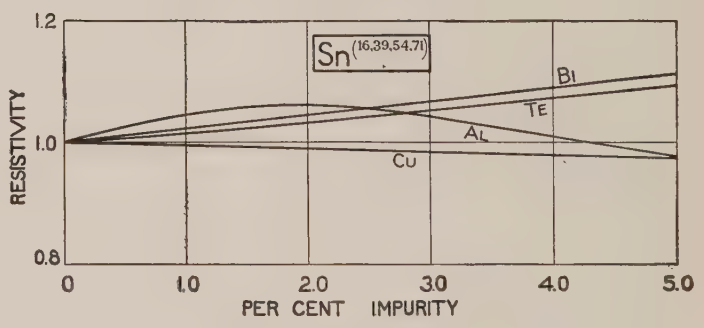
1.75
1.50
1.25
1.00
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY


Sn(16,39,54,71)
BI
TE
AL
CU
RESISTIVITY
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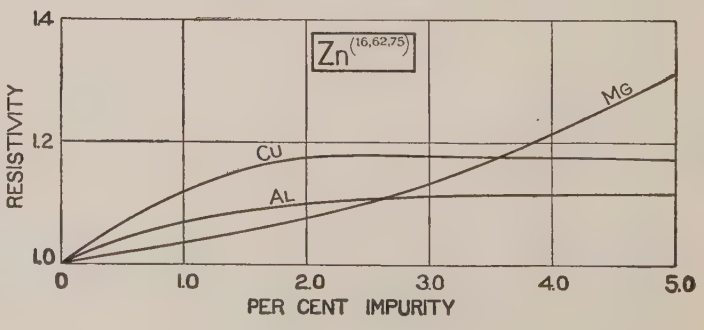
1.0
0.8
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY


Zn(16,62,75)
MG
CU
AL
RESISTIVITY
1.4
1.2
1.0
0
1.0
2.0
3.0
4.0
5.0
PER CENT IMPURITY

LITERATURE

(For a key to the periodicals see end of volume)

(1) Addicks, *80*, **36**: 18; 06. (2) Barratt, *67*, **26**: 347; 14. (3) Benedicks, *20*, **6**: No. 24; 11. (4) Benedicks, *95*, **7**: 225; 15. (5) Bidwell, *2*, **19**: 447; 22. (6) Bornemann and von Rauschenplat, *192*, **9**: 505; 12. (7) Bridgman, *65*, **52**: 573; 17. (8) Bridgman, *65*, **56**: 59; 21. (9) Bridgman, *65*, **57**: 41; 22. (10) Bridgman, *65*, **58**: 151; 23. (11) Bridgman, *65*, **59**: 107; 24. (12) Bridgman, *65*, **59**: 119; 24. (13) Bridgman, *65*, **60**: 385; 25. (14) Bridgman, *65*, **60**: 423; 25. (15) Bridgman, *197*, **10**: 411; 24. (16) Broniewski, *6*, **25**: 5; 12. (17) Broniewski and Hackspill, *34*, **153**: 814; 11. (18) Burgess and Aston, *78*, **20**: 205; 11. (19) Clausing, *208*, **4**: 374; 24.

(20) Davey, W. P., Pennsylvania State College, State College, Pa., *0*. (21) Dellinger, *31A*, **7**: 71; 11. (22) Dewar and Fleming, *3*, **34**: 326; 92. (23) Dewar and Fleming, *3*, **36**: 271; 93. (24) Dewar and Fleming, *5*, **60**: 72; 97. (25) Dewar and Fleming, *5*, **60**: 76; 97. (26, 27) Edwards, J. D., Aluminum Company of America, New Kensington, Pa., *0*. (28) Ellis, *Thesis*, Rensselaer Polytech. Inst., 1927. (29) Erhard, *8*, **14**: 504; 81.

(30) Eucken and Gehlhoff, *88*, **14**: 169; 12. (31) Feussner, *88*, **10**: 109; 91. (32) Feussner and Lindeck, *89*, **2**: 501; 95. (33) Fleming, *5*, **66**: 50; 00. (34) Forsythe, Nela Park, Cleveland, Ohio, *0*. (35) Geiss and van Liempt, *95*, **17**: 194; 25. (36) Guillaume, *34*, **115**: 414; 92. (37) Guntz and Broniewski, *42*, **7**: 464; 09. (38) Hackspill, *34*, **151**: 305; 10. (39) Haken, *8*, **32**: 291; 10.

(40) Hansen, *78*, **16**: 329; 09. (41) Heuer, *1*, **49**: 2711; 27. (42) Hunter, Sebast and Jones, *80*, **68**: 750; 23. (43) Ingersoll, *2*, **16**: 126; 20. (44) International Electrotechnical Commission, *Publication No.* **28**; 14. (45) International Conference on Electrical Units and Standards, 1908. London, H. M. S. O., 1909. (46) Jaeger and Diesselhorst, *89*, **3**: 269; 00. (47) Jaeger and Steinwehr, *8*, **45**: 1089; 14. (48) Koenigsberger and Schilling, *8*, **32**: 179: 10. (49) Kreichgauer and Jaeger, *8*, **47**: 513; 92.

(50) Kuh, *Thesis*, Zürich, 1911. (51) Kurnakov and Nikitinski, *93*, **88**: 151; 14. (52) Kurnakov and Zemczuzny, *93*, **64**: 149; 09. (53) Langmuir, *120*, **19**: 208; 16. (54) Ledoux, *34*, **155**: 35; 12. (55) Lees, *62*, **208**: 381; 08. (56) Matthiessen, *3*, **13**: 81; 57. (57) Matthiessen and Bose, *8*, **115**: 352; 62. (58) Meyer, *88*, **13**: 680; 11. (59) Mueller, E. F., Bureau of Standards, Washington, D. C., *0*.

(60) Müller, *192*, **7**: 755; 10. (61) Niccolai, *22*, **16 I**: 906; 07. (62) Norsa, *34*, **155**: 348; 12. (63) Northrup, *78*, **20**: 185; 11. (64) Northrup, *78*, **25**: 373; 14. (65) Northrup, *143*, **177**: 1; 14. (66) Northrup, *143*, **177**: 287; 14. (67) Northrup, *143*, **178**: 85; 14. (68) Northrup, *143*, **175**: 153; 13. (69) Oberbeck and Bergmann, *8*, **31**: 792; 87.

(70) Ryschewitsch, *9*, **29**: 474; 23. (71) Schulz, *8*, **9**: 555; 02. (72) Shukov, *53*, **42**: 40; 10. (73) Smirnov and Kurnakov, *93*, **72**: 31; 11. (74) Smith, *62*, **204**: 57; 04. (75) Stepanov, *93*, **78**: 1; 12. (76) Swisher, *2*, **10**: 601; 17. (77) Urasov, *93*, **73**: 31; 12. (78, 79, 80) Wenner and Lindberg, *0*.

(81) Wolff and Dellinger, *31A*, **7**: 103; 11. (82) Worthing, A. G., Univ. of Pittsburgh, *0*. (83) Zwikker, *208*, **5**: 249, 319; 25.

ELECTRICAL RESISTIVITY OF S, Se, AND Te

F. C. Brown and A. M. MacMahon

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Owing to the remarkable effect of light upon Se and to the chemical analogy of Se to S and to Te, it is convenient to devote a special section to the electrical resistivities of these three substances. Not only their chemical analogies, but also the differences in their resistivities and in their response to light, may be interpreted in terms of the outer electronic structures of the atoms (17). In general the resistivity depends upon the potential gradient (dV/dx) (1, 8); those tabulated below refer to relatively small values of the gradient.

Symbols

I = intensity (energy) of illumination; i_l, i_d = current when illuminated, when in the dark; P = pressure; t = temperature, °C; t_R = room temperature; V = applied potential; b, c, k = factors of proportionality; λ = wave-length of the illuminating radiation; ρ = resistivity.

RESISTIVITY (ρ) IN THE DARK

$P = 1$ kg/cm²; $\rho \equiv A \times 10^n$. Unit of ρ = 1 ohm-cm

Element	Form	t	A	n	Lit.
S	Orthorhombic α	20	1.91	17	(7)
	Orthorhombic α	30	3.90	16	(7)
	Monoclinic β	69	3.93	15	(9)
	Monoclinic β	112	7.39	12	(9)
	Liquid	130	2.0	10	(31)
	Liquid	300	2.8	8	(20)
	Liquid (*see also* p. 153)	440	7.7	6	(20)
Se	Vitreous	t_R	8.0	6	(27)
	Vitreous*	22	4.2	7	(18)
	Hexagonal ⊥ †	20	1.0	7	(4)
	Hexagonal ∥ §	24	1.93	6	(18)
	Annealed ¶	t_R	4.0	5	(27, 30)
	Annealed ¶	22	4.43	5	(18)
Se.—(*Continued*)	Liquid	390	7.66	4	(21)
	Liquid	437	2.23	4	(21)
	Liquid	540	2.24	3	(21)
	Liquid	690	8.8	1	(21)
Te	α ‡	20	2.5	−1	(14)
	β	20	5.9	−3	(14)
	$\alpha + \beta$ **	−200	4.9	−2	(13)
	$\alpha + \beta$ **	−100	6.7	−2	(13)
	$\alpha + \beta$ **	+ 55	1.2	−1	(13)
	$\alpha + \beta$ **	100	9.8	−2	(13)
	$\alpha + \beta$ **	200	4.7	−2	(13)
	$\alpha + \beta$ **	300	6.0	−3	(13)
	$\alpha + \beta$ ** (*see also* p. 129)	400	9.0	−3	(13)

* P = 1.5 kg/cm².

† Current ⊥ long axis, P small; at P = 150 kg/cm², $\rho = 10^5$.

‡ $\frac{1}{\rho}\frac{d\rho}{dt} = -0.63$ % per 1°C.

§ Current ∥ long axis, $P = -1.05$ kg/cm², $\frac{1}{\rho}\frac{d\rho}{dt} = -2.57$% per 1°C.

¶ Annealed at 200°C, $P = 6.15$ kg/cm²; $\frac{1}{\rho}\frac{d\rho}{dt} = -4$ to -6% per 1°C (27, 30), $= -0.817$% per 1°C (18).

** $\frac{1}{\rho}\left(\frac{d\rho}{dp}\right)_{t=0} = -0.0129$% per kg/cm² (2).

EFFECT OF LIGHT

Sulfur.—For rhombic, or α-sulfur, the form stable at ordinary temperatures, $i_l - i_d$ is very small if dV/dx is small (11); it increases with dV/dx to a limiting value at dV/dx a little greater than 30 000 volt/cm; $i_l - i_d = kI$, where k is independent of I (15) but varies with λ, having a maximum at $\lambda = 470\text{m}\mu$ ($= 470 \times 10^{-7}$ cm).

Selenium.—Resistivity of crystalline Se is greatly reduced by illumination (28), but the decrease depends upon so many factors that it is impracticable at this time to give numerical constants of general applicability. The value of i_l depends upon the form and dimensions of the constituent crystals, upon the quality, intensity and duration of the illumination, as well as upon the temperature, pressure and applied potential difference; it varies with λ, passing through a well-defined maximum in the red (6, 25, 26). The variation of i_l with I is still under discussion (23); Brown (4) found $i_l = i_d e^{bI}$. Recently Piersol (22) confirmed the conclusion of

Rosse (24) that $i_l - i_d = C\sqrt{I}$, provided I is neither very small nor extremely great; here b and C are independent of I but dependent upon λ and other physical parameters. For dependence of i_l upon duration of illumination, *see* (3, 10, 16, 29); for a more complete bibliography of the entire subject, *see* (5, 12, 23).

Typical Data for Selenium Bridges

Annealed Bridge of the Braun Condenser Type (16). Useful area = 151 mm²; thickness = 0.1 to 0.2 mm. Unit of λ = 1mμ = 10^{-7} cm; of $I_\lambda = 10^{-8}$ watt/mm²; of V = 1 volt; of i_d, $i_l = 10^{-5}$ ampere.

λ	I_λ	V	i_d	$i_l - i_d$	V	i_d	$i_l - i_d$
451	2.83	5.60	15.7	1.09	11.03	34.9	2.23
529	4.07	5.60	15.6	1.76	11.02	34.7	3.56
674	3.68	5.35	14.7	4.26	10.70	33.8	9.78

Crystal Bridge (19). Useful area = 132 mm²; thickness = 0.2 to 0.3 mm; illumination by gas-filled tungsten (W) lamp, total unfiltered radiation; I = 0.5 phot. = 0.5 lumen/cm² = 5000 m-candle = 464 ft. candle. Unit of V = 1 volt; of i_d, i_l = 1 ampere.

V	i_d	$i_l - i_d$	V	i_d	$i_l - i_d$
2.0	1.11×10^{-4}	1.80×10^{-4}	20.0	1.43×10^{-3}	1.56×10^{-3}

Tellurium.—Some observers, neglecting effects due to the high thermoelectric power of Te with respect to other metals, have concluded that the resistivity of Te is affected by illumination. Careful investigation shows that this conclusion is incorrect (18). The absence of such an effect is in agreement with a recent interpretation of the low resistivity of Te (17).

LITERATURE

(For a key to the literature see end of volume)

(1) Adams, *5*, **23**: 535; 75. **24**: 163; 75. (2) Bridgman, *197*, **3**: 10; 17. (3) Brown, *2*, **33**: 1, 403; 11. (4) Brown, *2*, **4**: 85; 14. (5) Brown, *453*, **23**: 241; 16. (6) Brown and Sieg, *2*, **4**: 48; 14. (7) Curtis, *31A*, **11**: 359; 15. (8) Fournier d'Albe, *5*, **86**: 452; 12. (9) Foussereau, *34*, **97**: 996; 83.
(10) Glatzel, *88*, **13**: 778; 11. **14**: 607; 12. (11) Goldmann and Kalandyk, *8*, **36**: 589; 11. (12) Graetz, *Handbuch der Elektrizität und des Magnetismus*, **III**: 681; 23. Leipzig, Barth. (13) Guntz and Broniewski, *34*, **147**: 1474; 08. (14) Haken, *8*, **32**: 291; 10. (15) Kurrelmeyer, *2*, **29**: 615; 27. (16) MacMahon, *2*, **29**: 219; 27. (17) MacMahon, *2*, **29**: 902; 27. (18) MacMahon, Univ. Chicago, *0*. (19) MacMahon and Brown, *48*, **11**: 221; 25.
(20) Monckmann, *5*, **46**: 136; 89. (21) Pelabon, *34*, **173**: 295; 21. (22) Piersol, *2*, **29**: 902; 27. (23) Ries, *Das Selen*, p. 95. Hüber, München, 1918. (24) Rosse, *3*, **47**: 161; 74. (25) Sale, *5*, **21**: 283; 73. (26) Sieg and Brown, *2*, **5**: 65; 15. (27) Siemens, *8*, **159**: 117; 76. (28) Smith, *58*, **7**: 303; 73. (29) Sperling, *Diss.*, Göttingen, 1908.
(30) Stebbins and Brown, *21*, **26**: 326; 07. (31) Wigand, *88*, **10**: 495; 08.

THE ELECTRICAL CONDUCTIVITY OF PURE NON-METALLIC LIQUIDS[1]

J. R. Partington

Abbreviations.—"Non." = a "non-conductor." κ = conductivity in ohm^{-1}cm^{-1}.

Elementary Substances* and Atmospheric Air; A-Table

Substance	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
Br	17.2	13	14	(36); *cf.* (122, 144); Fig. 6
Cl	−70(?)	<1	16	(81)
I	110	13	11	(36, 143); *cf.* Fig. 6
P	25	4	7	(37, 38); *cf.* Fig. 7
S	115	1	12	(37)
	130	5	11	(135)
	440	12	8	(87)
Se	*v.* p. 141			
Air		*ca.* 0		(27)
Air under Ra rays		13	15	(27)

* Except data below −80°C, for which *v.* p. 124.

Chemical Compounds, B-Table

Standard arrangement; *v.* Vol. III, p. viii

Substance	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
H_2O	18	4	8	*v.* p. 152
HCl	−96	1	8	(2)
HBr	−80	8	9	(1)
HI	B. P.(?)	2	7	(114)
SO_2; *cf.* (18, 19, 31, 132, 133)	−15	9*	8	(34)
	(?)	<5	8	(13)
	35	15	8	(4)
SO_3		"Non."		(122)
H_2S	B. P.(?)	1	11	(96.5); *cf.* (114)
H_2SO_4	25	1	2	(7); *cf.* (48)

[1] Except fused salts, for which *see* p. 147.

B-Table.—(*Continued*)

Substance	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
S_2Cl_2	25	"Non."		(122)
$SOCl_2$	25	2	6	(122)
SO_2Cl_2	25	3	8	(124)
SO_2OHCl	25	16	5	(123)
$SeOCl_2$	25	2	5	(64)
$SeOBr_2$	45 to 50	6	5	(78)
NH_3; *cf.* (18, 19)	−33	<1	8	(39, 40)
	−79	13	8	(41)
$2H_3PO_4.H_2O$		*ca.* 1	2	(97)
PCl_5		>"Non."		(122)
$POCl_3$	25	22	7	(122)
PBr_5		"Non."		(122)
$AsCl_3$	25	12	7	(124)
$AsBr_3$	35	15	7	(123)
$SbCl_3$	75(?)	85	8	(73)
$SbCl_5$		"Non."		(122)
Sb_2S_3	*See* Fig. 8			(75)
Carbon compounds, *v. infra.*				
$SiCl_4$		"Non."		(122)
$Si(OCH_3)_4$	25	16	7	(84)
$Si(OC_2H_5)_4$	25	<3	8	(84)
$GeBr_4$	30	78	6	(30)
$SnCl_4$		"Non."		(122)
OsO_4	40(?)	<1	11	(134.5)
$Ni(CO)_4$		1	9	(85)
BCl_3		"Non."		(122)
$B(OCH_3)_3$	0	5	6	(127)
	25	6	6	
NaOH, KOH	400 to 600			(3)

* Probably high.

Carbon Compounds; ℭ-Table; *v.* Vol. III, p. viii

Natural oils at end of table; for anisotropic liquids, *v.* (116)

Formula	Name	*t*, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
CBrN	Cyanogen bromide	55	*ca.* 2	2	(43)
CCl_4	Carbon tetrachloride	18	4	18	(8); *cf.* (55)
CCl_2O	Carbonyl chloride	25	7	9	(42.5)
CN_4O_8	Tetranitromethane		"Non."		(127)
CS_2	Carbon disulfide	18	78	19	(8); *cf.* (55, 76, 97.2)
$CHBr_3$	Bromoform	25	< 2	8	(93)
$CHCl_3$	Chloroform	25	< 2	8	(93); *cf.* (126)
CHN	Hydrogen cyanide	0	33	7	(129); *cf.* (18, 19, 22, 68)
CH_2O_2; *cf.* (17, 91, 105, 107, 129)	Formic acid	18	56	6	(106)
		25	64	6	
CH_3I	Methyl iodide	25	< 2	8	(93); *cf.* (101)
CH_3NO	Formamide	0	18*	6	(127)
		19	18*	5	(129)
		25	4	6	(70)
CH_3NO_2	Nitromethane	0	44	8	(125)
		18	6	7	(12); *cf.* (26, 95)
		25	54	8	(125)
CH_3NO_3	Methyl nitrate	25	45	7	(93)
CH_4O; *cf.* (18, 19, 60, 61, 98, 102, 115, 121)	Methyl alcohol	(?)	4	8	(51.5); *cf.* (62)
		18	44	8	(117)
		20	58	7	(108)
		25	22	8	(133.5); *cf.* (127)
CH_5N	Methylamine		*ca.* 7	7	(38.5)
C_2N_2	Cyanogen		< 7	9	(22)
C_2HBr_3O	Bromal	25	8	8	(99)
$C_2HCl_3O_2$	Trichloroacetic acid	25	3	9	(69); *cf.* (97.1)
		60	62	10	(70)
C_2H_2	Acetylene		"Non."		(82)
$C_2H_2Br_2O$	Bromoacetyl bromide	0	73	8	(124)
$C_2H_2Cl_2O_2$	Dichloroacetic acid	0	4	8	(97.1)
		25	7	8	
C_2H_3BrO	Acetyl bromide	0	2	6	(127)
		25	24	7	(127)
C_2H_3ClO	Acetyl chloride	0	35	8	(127)
		25	4	7	(127)
$C_2H_3ClO_2$	Chloroacetic acid	60	14	7	(70)
C_2H_3N	Acetonitrile	0	1	6	(125); *cf.* (100)
		20	7	6	(42)
		25	19	8	(127)
C_2H_3NO	Glycolic nitrile	0	52	7	(125)
		25	83	7	
C_2H_3NS	Methyl thiocyanate	0	13	7	(130); *cf.* (65)
		25	15	7	
C_2H_3NS	Methyl isothiocyanate†	50	3	7	(125)
$C_2H_4Cl_2$	1, 1-Dichloroethane	25	<17	9	(101)
$C_2H_4Cl_2$	Ethylene chloride	25	3	8	(131)
$C_2H_4Br_2$	Ethylene bromide	19	< 2	10	(42)
C_2H_4O	Acetaldehyde	0	14	7	(125, 127)
		15	17	7	(127)
		20.5	55	7	(42)
$C_2H_4O_2$; *cf.* (46, 49, 58, 69, 70)	Acetic acid	0	5	9	(97.1)
		18	5*	7	(54)
		25	11.2	9	(97.1)
		30	8	9	(54)
		40	14*	8	(54)
		(?)	8	10	(14.5)
$C_2H_4O_2$	Methyl formate; *see* Fig. 3				
C_2H_4OS	Thioacetic acid	0	39	7	(127)
		25	27	7	
C_2H_5Br	Ethyl bromide	25	< 2	8	(93)
C_2H_5I	Ethyl iodide	25	< 2	8	(93)
C_2H_5NO	Acetamide	100	<43	6	(134); *cf.* (6.5)
$C_2H_5NO_3$	Ethyl nitrate	0	23	8	(127); *cf.* (101); *see also* Fig. 2)
		25	53	8	
C_2H_6O; *cf.* (18, 19, 26, 44, 61, 62, 63, 66, 76, 92, 117, 119, 120)	Ethyl alcohol	0	15*	8	(127)
		18	64*	9	(121)
		25	135	11	(28)

* Probably high.

ℭ-Table.—(*Continued*)

Formula	Name	*t*, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
$C_2H_6O_2$	Glycol	0	24	8	(127)
		25	3	7	(130)
$C_2H_6O_4S$	Dimethyl sulfate	0	16	8	(127)
		25	3	7	
$C_2H_6N_2O$	Dimethylnitrosamine	0	12	6	(127); *cf.* (129)
		25	16	6	
C_2H_7N	Ethylamine	−33.5	46	9	(35)
		0	4	7	(113)
C_3H_4O	Acrolein (not quite pure; had an acid reaction)	10	16	8	(89)
C_3H_5ClO	Epichlorohydrin	25	34	9	(127); *cf.* (26, 112)
$C_3H_5ClO_2$	Ethyl chloroformate				(5)
C_3H_5N	Propionitrile	25	< 1	7	(125); *see* Fig. 6
C_3H_5NO	Lactonitrile(α-hydroxypropionitrile)	0	18	8	(127)
		25	31	8	
C_3H_5NS	Ethyl isothiocyanate	0	87	9	(127)
		25	126	9	
C_3H_5NS	Ethyl thiocyanate	25	12	7	(127)
$C_3H_6Cl_2O$	Dichlorohydrin	25	12	6	(101)
C_3H_6O; *cf.* (26, 42, 112)	Acetone	−15	11	10	(130)
		0	6	8	(61)
		18	2	8	(32)
		20	12*	8	(108)
		25	6	8	(69, 70)
C_3H_6O	Allyl alcohol	25	7	6	(80)
C_3H_6O	Propionaldehyde	0	7	7	(125); *cf.* (26)
		25	85	8	
$C_3H_6O_2$	Ethyl formate, *see* Fig. 2				
$C_3H_6O_2$	Methyl acetate	25	34	7	(93); *cf.* Fig. 3
$C_3H_6O_2$	Propionic acid	25	< 1	9	(70)
$C_3H_6OS_2$	Ethyl xanthogenate(?)	25	< 2	8	(93)
C_3H_7Br	*n*-Propyl bromide	25	< 2	8	(93)
$C_3H_7ClO_2$	Chlorohydrin	25	5	7	(101)
C_3H_8O	*n*-Propyl alcohol	18	5	8	(32); *cf.* (59, 104)
		25	2	8	(72)
		25	9	9	(11)
C_3H_8O	Isopropyl alcohol	25	35	7	(101)
$C_3H_8O_3$	Glycerol	25	64	9	(29); *cf.* (20, 47, 108, 109)
C_3H_9N	Trimethylamine	−33.5	22	11	(35)
$C_4H_4N_2$	Succinonitrile	60	15	7	(125)
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	25	3	8	(97.1); *cf.* (5)
$C_4H_5NO_2$	Methyl cyanoacetate	0	3	7	(127); *see* Fig. 7
		25	45	8	
C_4H_5NS	Allyl isothiocyanate	25	25	6	(84); *cf.* (65)
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate	25	7	8	(97.1); *cf.* (5)
$C_4H_6O_3$	Acetic anhydride	0	1	6	(125)
		20	75*	8	(108)
		25	48	8	(127)
$C_4H_7ClO_2$	Ethyl chloroacetate	25	2	7	(97.1); *cf.* (80)
C_4H_7N	*n*-Butyronitrile	25	12	6	(33)
$C_4H_8Br_2$	Butylene bromide	25	< 2	8	(93)
C_4H_8O	Methyl ethyl ketone	25	1	7	(95)
$C_4H_8O_2$	Ethyl acetate	25	< 1	9	(69, 71); *cf.* (101)
$C_4H_8O_2$	Propyl formate; *see* Fig. 1				
$C_4H_8O_2$	Methyl propionate; *see* Fig. 3				
$C_4H_9NO_3$	Isobutyl nitrate	25	< 2	8	(93); *see* Fig. 1
$C_4H_{10}O$	Ether	25	< 4	13	(97.2); *cf.* (18, 19, 21, 42, 76, 124)
$C_4H_{10}O$	Isobutyl alcohol	18	< 1*	7	(32); *cf.* (101)
		25	8	8	(131)
		25	95	10	(11)
$C_4H_{10}O_3S$	*asym.*-Diethyl sulfite	0	3	7	(127)
		25	5	7	
$C_4H_{10}O_3S$	*sym.*-Diethyl sulfite	0	2	7	(127)
		25	4	7	
$C_4H_{10}O_4S$	Diethyl sulfate	0	16	8	(127)
		25	26	8	
$C_4H_{11}N$	Diethylamine	−33.5	22	10	(35)

† In the original, the compound in question is called "methylene mustard oil," and the formula "CN.CNS" is given. The boiling point (117°) indicates, however, that the liquid is probably methyl mustard oil.

℄-Table.—(*Continued*)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
$C_5H_4O_2$	Furfural	0	97	8	(127)
		20	11	7	(108); *cf.* (101)
		25	15	7	(127)
		25	16	8	(128)
$C_5H_4O_3$	Citraconic anhydride	0	1	7	(127)
		25	2	7	
C_5H_5N; *cf.* (51, 52, 80, 96)	Pyridine	0	57*	9	(94)
		18	53	9	(32)
		25	< 5	8	(79)
		25	68	9	(50)
$C_5H_7NO_2$	Ethyl cyanoacetate	0	19	8	(127); *cf.* (80)
		25	19	8	
$C_5H_8O_2$	Acetylacetone	0	2	7	(127)
		25	3	7	
$C_5H_8O_4$	Dimethyl malonate	0	8	8	(127)
		25	12	8	
C_5H_9N	Valeronitrile	25	57	7	(101)
C_5H_{10}	Amylene (fusel amylene)	25	< 2†	8	(93)
$C_5H_{10}O$	Isovaleraldehyde	0	8	8	(125)
		25	10	8	
$C_5H_{10}O$	Methyl propyl ketone	25	1	6	(80)
$C_5H_{10}O_2$	Ethyl propionate; *see* Fig. 2				
$C_5H_{10}O_2$	Isovaleric acid	80	< 4	13	(97.2)
$C_5H_{10}O_2$	Isobutyl formate; *see* Fig. 1				
$C_5H_{10}O_2$	Methyl butyrate; *see* Fig. 3				
$C_5H_{10}O_2$	Propyl acetate; *see* Fig. 1				
$C_5H_{10}O_3$	Diethyl carbonate	25	17	9	(101)
			See also Fig. 2		
$C_5H_{11}Br$	Isoamyl bromide	25	< 2	8	(93)
$C_5H_{11}I$	Amyl iodide	25	35	7	(93)
$C_5H_{11}N$	Piperidine	25	< 2	7	(80)
$C_5H_{11}NO_2$	Amyl nitrite	25	19	8	(80)
$C_5H_{11}NO_3$	Amyl nitrate	25	28	8	(101); *see* Fig. 3
C_6H_{12}	Pentane	19.5	< 2	10	(42)
$C_5H_{12}O$	Isoamyl alcohol	18	5*	8	(44); *cf.* (42, 96)
		20	4*	8	(108)
		25	15	9	(72)
$C_5H_{12}S$	Amyl hydrogen sulfide (amylmercaptan)	25	< 2	8	(93)
$C_5H_{13}N$	Isoamylamine	25	< 8	8	(67)
C_6H_5Br	Bromobenzene	25	< 2	11	(97.2); *cf.* (24, 101)
$C_6H_5NO_2$; *cf.* (14, 66, 86)	Nitrobenzene	0	5	9	(97.2)
		18	2*	7	(26)
		20	< 2	10	(42)
		25	< 2*	8	(93)
C_6H_6	Benzene		76	9	(15, 23, 55, 74, 76, 93, 111, 118, 126)
			< 1	18	
C_6H_6ClN	*m*-Chloroaniline	25	5	8	(100); *cf.* (131)
C_6H_6O	Phenol	25	<17	9	(101)
C_6H_7N	Aniline	0	9‡	9	(94)
		25	24	9	
		35	82	9	
C_6H_7N	Picoline	25	55	8	(101)
$C_6H_{10}O_3$	Ethyl acetoacetate	25	4	8	(66); *cf.* (45, 131)
$C_6H_{10}O_4$	Diethyl oxalate	25	76	8	(80); *cf.* (101)
$C_6H_{10}O_5$	Dimethyl malate	0	3	7	(127)
		25	55	8	(126)
$C_6H_{11}N$	Capronitrile	25	37	7	(101)
$C_6H_{11}NS$	Amyl thiocyanate	25	15	6	(65)
$C_6H_{12}O_2$	Amyl formate; *see* Fig. 3				
$C_6H_{12}O_2$	Ethyl butyrate; *see* Fig. 2				
$C_6H_{12}O_2$	Ethyl isobutyrate; *see* Fig. 2				
$C_6H_{12}O_2$	Isobutyl acetate; *see* Fig. 1				
$C_6H_{12}O_2$	Methyl valerate; *see* Fig. 3				
$C_6H_{12}O_2$	Propyl propionate; *see* Fig. 1				
$C_6H_{12}O_3$	Paraldehyde		<36	8	(80)
C_6H_{14}	Hexane	18	< 1§	18	(8); *cf.* (24, 56, 57, 111)
C_7H_5N	Benzonitrile	25	5	8	(131); *cf.* (79)

* Probably high.

† $\kappa = 14 \times 10^{-14}$ under the influence of radium rays; "almost a perfect insulator when shielded from the rays" (27).

‡ No noticeable change in conductivity on darkening.

§ The conductivity of the liquid decreases when enclosed by a lead mantle (111).

℄-Table.—(*Continued*)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
C_7H_5NS	Phenyl isothiocyanate	25	14	7	(84)
C_7H_6O	Benzaldehyde	18	17	8	(26)
		20	4	7	(42, 108)
		25	15	8	(26, 125)
$C_7H_6O_2$	Benzoic acid	125‖	3	9	(97.2)
$C_7H_6O_2$	Salicylaldehyde	0	1	7	(125)
		25	16	8	(80)
$C_7H_7NO_2$	*o*-Nitrotoluene	25	< 2	7	(80)
$C_7H_7NO_2$	*m*-Nitrotoluene	25	< 2	7	(80)
C_7H_8	Toluene		< 1	14	(23); *cf.* (76, 110, 111)
C_7H_8O	Benzyl alcohol	25	18	7	(80)
C_7H_8O	*m*-Cresol	25	<17	9	(101)
$C_7H_8O_2$	Guaiacol	25	28	8	(101)
C_7H_9N	Benzylamine	25	<17	9	(101)
C_7H_9N	*o*-Toluidine	25	< 2	6	(101)
C_7H_9N	*p*-Toluidine	100	62	9	(6)
$C_7H_{12}O_4$	Diethyl malonate		"Non."; *see* Fig. 2		(90)
$C_7H_{14}O_2$	Amyl acetate; *see* Fig. 3				
$C_7H_{14}O_2$	Ethyl valerate; *see* Fig. 2				
$C_7H_{14}O_2$	Propyl butyrate; *see* Fig. 1				
C_7H_{16}	Heptane		< 1	13	(24, 56)
C_8H_7N	Benzyl cyanide	0	1	7	(127); *cf.* (108)
		25	< 5	8	(131)
C_8H_7N	Tolunitrile	25	57	7	(101)
C_8H_8O	Acetophenone	16.5	21	8	(25); *cf.* (69, 80)
		25	6	9	(88)
$C_8H_8O_2$	*p*-Methoxybenzaldehyde (anisaldehyde)	0	8	8	(128)
		20	86	9	(108)
		25	12	8	(130)
$C_8H_8O_2$	Methyl benzoate; *see* Fig. 3				
C_8H_{10}	Xylene		< 1	15	(16); *cf.* (24, 76)
$C_8H_{10}O$	*o*-Cresyl methyl ether	25	<17	9	(101)
$C_8H_{10}O$	Phenetole	25	<17	9	(101)
$C_8H_{14}O_3$	Isobutyric anhydride	0	1	7	(125)
		25	16	8	
$C_8H_{14}O_4$	Diethyl succinate; *see* Fig. 2				
$C_8H_{16}O_2$	Caprylic acid	80	< 4	13	(97.2)
$C_8H_{16}O_2$	Amyl propionate; *see* Fig. 3				
$C_8H_{16}O_2$	Isobutyl butyrate; *see* Fig. 1				
$C_8H_{16}O_2$	Propyl valerate; *see* Fig. 1				
C_9H_7N	Quinoline	0	16	9	(94); *cf.* (101)
		25	22	9	
		50	74	9	
$C_9H_{10}O_2$	Ethyl benzoate	19	< 2	10	(42)
		25	< 1	9	(69, 70, 71)
$C_9H_{14}O_6$	Triacetin; *see* Fig. 4				
$C_9H_{18}O_2$	Amyl butyrate; *see* Fig. 3				
$C_9H_{18}O_2$	Isobutyl valerate; *see* Fig. 1				
C_9H_{20}	Nonane	25	<17	9	(101)
$C_{10}H_7Br$	Bromonaphthalene	25	4	11	(97.2)
$C_{10}H_8$	Naphthalene	82	4	10	(97.2); *cf.* (75)
$C_{10}H_{12}O_2$	Eugenol	25	<17	9	(101)
$C_{10}H_{14}$	Cymene	25	< 2	8	(93)
$C_{10}H_{16}$	*d*(*l*)-Limonene	18	3	12	(24)
		25	<17¶	9	(101)
$C_{10}H_{16}$	Pinene	23	< 2	10	(42)
$C_{10}H_{16}$	Terpinene	25	<17	9	(101)
$C_{10}H_{18}O$	Menthone	2	<17	9	(101)
$C_{10}H_{18}O$	α-Terpineol	25	<17	9	(101)
$C_{10}H_{18}O_2$	Acetylmethyl hexyl ketone	25	<17	9	(101)
$C_{10}H_{20}O_2$	Amyl valerate; *see* Fig. 3				
$C_{11}H_{12}O_2$	Ethyl cinnamate; *see* Fig. 2				
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	0	7	8	(127)
		25	8	8	(125)
$C_{11}H_{14}O_2$	Isobutyl benzoate; *see* Fig. 1				
$C_{12}H_{14}I_3N$	Quinolinium *n*-propyl triiodide; *see* Fig. 5				
$C_{12}H_{16}O_2$	Amyl benzoate	25	<17	9	(101)
$C_{13}H_{16}I_3N$	Quinolinium butyl and isobutyl triiodide; *see* Fig. 5				
$C_{14}H_8O_4$	Alizarin	233	99**	−4	(75)
$C_{14}H_{10}$	Anthracene	230	3	10	(97.2); *see* Fig. 8
$C_{14}H_{12}O_2$	Benzyl benzoate	25	< 1	9	(70, 71)

‖ Other temperatures also.

¶ Probably high.

** With a polarisation of 1.5 volt.

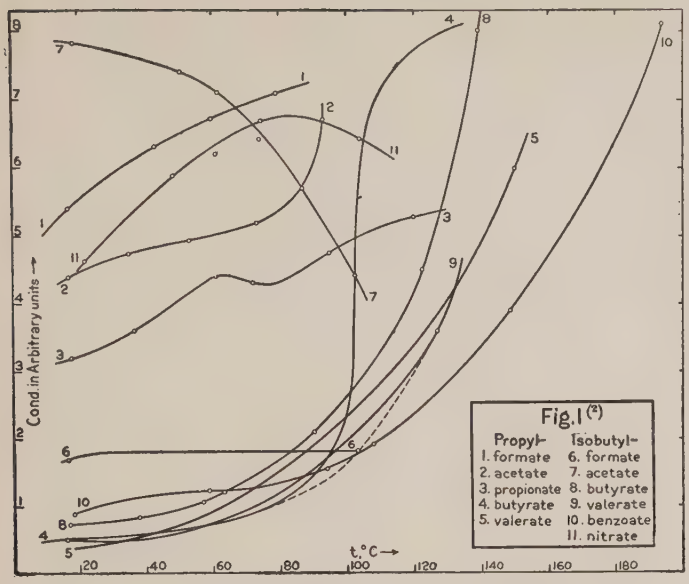


Fig.1 (2)
Propyl-
1. formate
2. acetate
3. propionate
4. butyrate
5. valerate
Isobutyl-
6. formate
7. acetate
8. butyrate
9. valerate
10. benzoate
11. nitrate
Cond. in Arbitrary units →
t, °C →

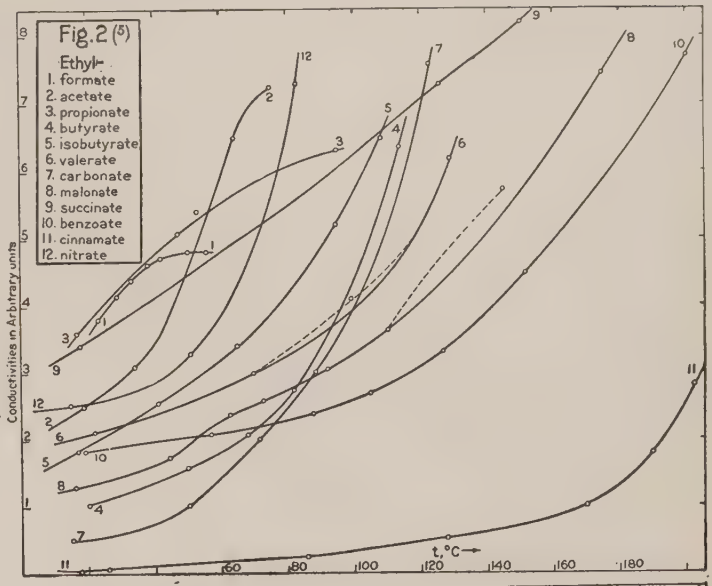
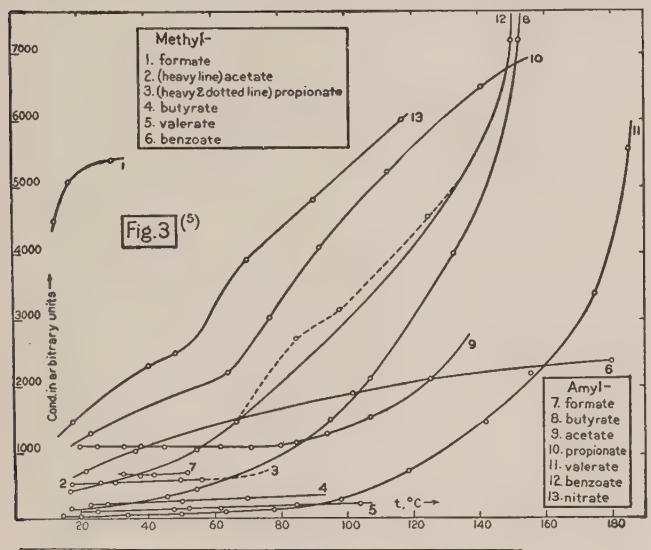


Fig.2 (5)
Ethyl-
1. formate
2. acetate
3. propionate
4. butyrate
5. isobutyrate
6. valerate
7. carbonate
8. malonate
9. succinate
10. benzoate
11. cinnamate
12. nitrate
Conductivities in Arbitrary units
t, °C →


Methyl-
1. formate
2. (heavy line) acetate
3. (heavy & dotted line) propionate
4. butyrate
5. valerate
6. benzoate
Fig.3 (5)
Amyl-
7. formate
8. butyrate
9. acetate
10. propionate
11. valerate
12. benzoate
13. nitrate
Cond. in arbitrary units →
t, °C →

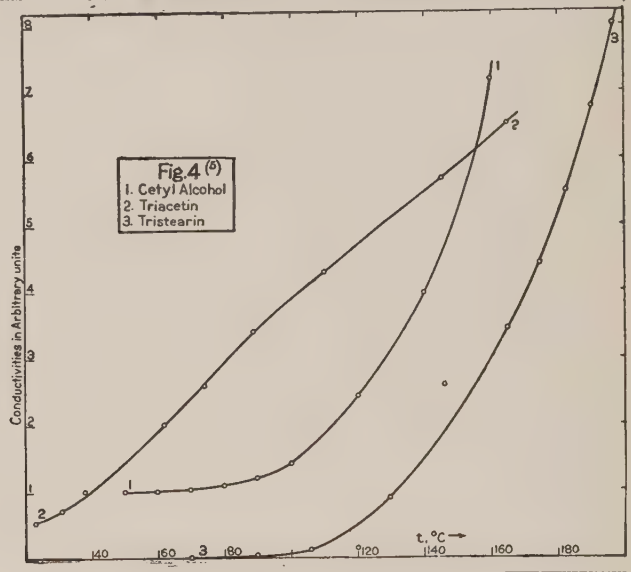


Fig.4 (5)
1. Cetyl Alcohol
2. Triacetin
3. Tristearin
Conductivities in Arbitrary units
t, °C →

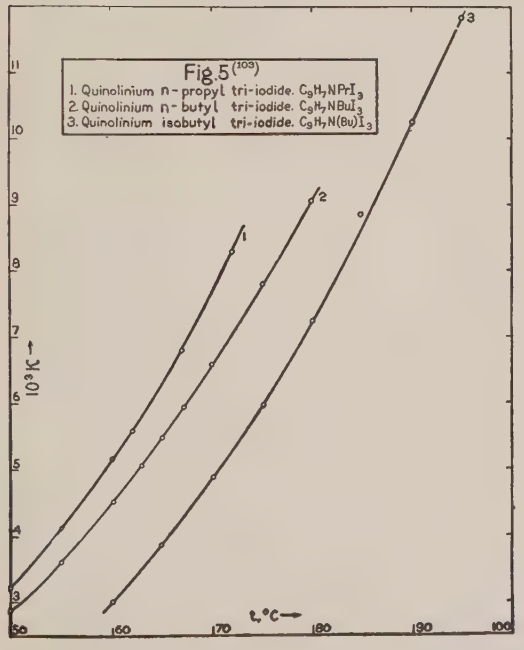


Fig.5 (103)
1. Quinolinium n-propyl tri-iodide. C9H7NPrI3
2. Quinolinium n-butyl tri-iodide. C9H7NBuI3
3. Quinolinium isobutyl tri-iodide. C9H7N(Bu)I3
10³ K →
t, °C →

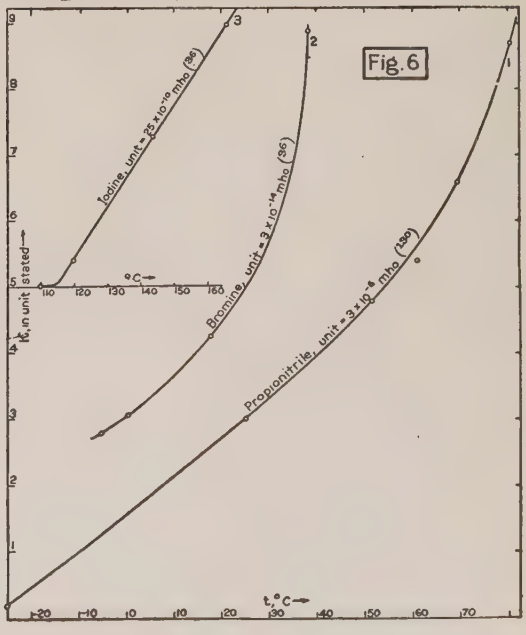


Fig.6
Iodine, unit = 2.5 x 10⁻¹⁰ mho (36)
Bromine, unit = 3 x 10⁻¹⁴ mho (36)
Propionitrile, unit = 3 x 10⁻⁶ mho (130)
K, in unit stated →
t, °C →

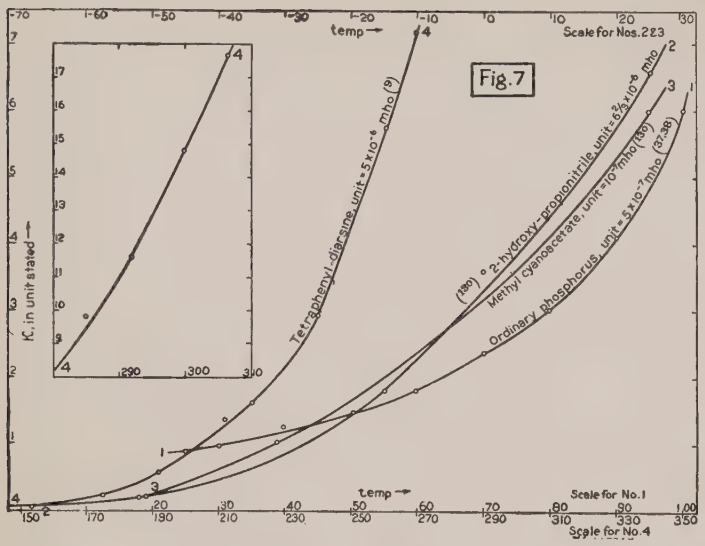
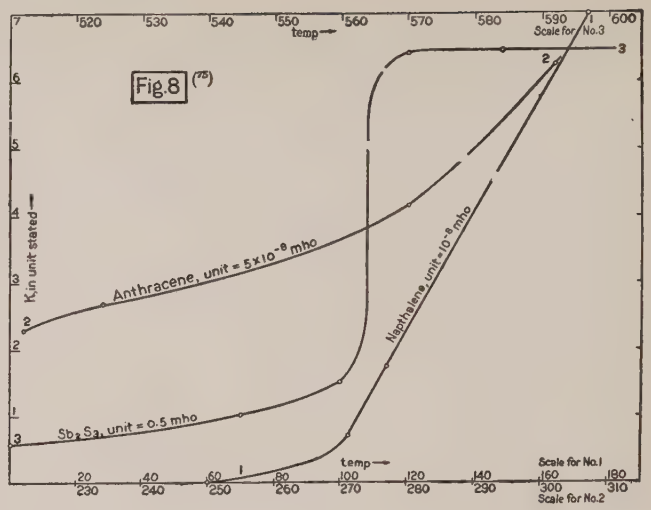


Fig.7
temp→
Scale for Nos.2 2 3
Tetraphenyl diarsine, unit = 5×10⁻⁶ mho (9)
(189°) α-hydroxy-propionitrile, unit = 6⅔×10⁻⁶ mho
Methyl cyanoacetate, unit = 10⁻⁵ mho (189°)
Ordinary phosphorus, unit = 5×10⁻⁷ mho (37.38°)
K, in unit stated
Scale for No.1
Scale for No.4



ℭ-Table.—(*Continued*)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
$C_{14}H_{15}N$	Dibenzylamine	25	17	9	(101)
$C_{16}H_{32}O_2$	Palmitic acid	80	< 4	13	(97.2)
$C_{16}H_{34}O$	Cetyl alcohol; *see* Fig. 4				
$C_{18}H_{34}O_2$	Oleic acid	15	< 2	10	(42)
$C_{18}H_{36}O_2$	Stearic acid	80	< 4	13	(97.2)
$C_{24}H_{20}As_2$	Tetraphenyldiarsine	151.5	47	8	(9); *see* Fig. 7
$C_{57}H_{110}O_6$	Tristearin; *see* Fig. 4				

Substance	t, °C	$\kappa = A \times 10^{-n}$ A	n	Lit.
Almond oil				(76)
Benzine		< 1	12	(10, 27, 83, 111)
Castor oil				(76)
Kerosene	25	<17	9	(101)
Ligroin		59	17	(118)
Linseed oil		1	16	(76)
Olive oil		1	13	(118); *cf.* (76)
Paraffin oil		7	17	(118); *cf.* (53)
Petroleum		3	13	(118)
Petroleum ether		34	16	(118); *cf.* (27)
		1	18	(55); *cf.* (27)
Turpentine		2	13	(83)
Vaseline (oil of)		8	17	(118); *cf.* (27, 76, 83)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Archibald, *1*, **29**: 665; 07. (2) Archibald, *1*, **29**: 1416; 07. (3) Arndt and Ploetz, *7*, **121**: 439; 26. (4) Bagster and Steele, *83*, **8**: 51; 12. (5) Bartoli, *36*, **24 II**: 156; 94. (6) Baskov, *53*, **45**: 1604; 13. (6.5) Belladen, *36*, **57**: 407; 27. (7) Bergius, *7*, **72**: 338; 10. (8) van der Bijl, *8*, **39**: 170; 12. (9) Borgstrom and Dewar, *1*, **44**: 2915; 22.

(10) Bouty, *6*, **27**: 62; 92. (11) Bregmann, *Diss.*, Lausanne. *10*, **4**: 931; 22. (12) Bruner, *25*, **36**: 3297; 03. (13) Bruner and Bekier, *7*, **84**: 570; 13. (14) Bruner and Galecki, *7*, **84**: 513; 13. (14.5) Bruns, *7*, **118**: 89; 25. (15) Cady and Lichtenwalter, *1*, **35**: 1434; 13. (16) Campbell, *3*, **23**: 668; 12. (17) Carrara and Levi, *36*, **32 II**: 36; 02. (18) Carvallo, *16*, **1**: 171; 14. (19) Carvallo, *16*, **2**: 142; 14.

(20) Cattaneo, *22*, **2 II**: 112; 93. (21) Cattaneo, *22*, **4 II**: 63; 95. (22) Centnerszwer, *7*, **39**: 217; 02. (23) di Ciommo, *96*, **4**: 291; 02. (24) di Ciommo, *59*, **3**: 97; 02. (25) Creighton, *7*, **81**: 543; 13. (26) Creighton and Way, *143*, **186**: 675; 18. (27) Curie, *34*, **134**: 420; 02. (28) Danner and Hildebrand, *1*, **44**: 2824; 22. (29) Davis and Jones, *7*, **81**: 68; 12.

(30) Dennis and Hance, *135*, **124**: 66; 22. (31) Dutoit, *9*, **12**: 642; 06. (32) Dutoit and Duperthuis, *42*, **6**: 699; 08. (33) Dutoit and Friderich, *27*, **19**: 321; 98. (34) Dutoit and Gyr, *42*, **7**: 189; 09. (35) Elsey, *1*, **42**: 2454; 20. (36) Exner, *8*, **15**: 412; 82. *75*, **84 II**: 511; 82. (37) Foussereau, *51*, **4**: 189; 85. (38) Foussereau, *6*, **5**: 317; 85. (38.5) Franklin and Gibbs, *1*, **29**: 1389; 07. (39) Franklin and Kraus, *11*, **23**: 277; 00.

(40) Franklin and Kraus, *1*, **27**: 191; 05. (41) Frenzel, *9*, **6**: 477; 00. (42) Gates, *60*, **15**: 97; 11. (42.5) Germann, *166*, **61**: 70; 25. (43) Glockler, *197*, **12**: 522; 26. (44) Godlewski, *42*, **3**: 393; 05. (45) Gomberg, *11*, **25**: 317; 01. (46) Grunmach, *8*, **28**: 217; 09. (47) Guy and Jones, *11*, **46**: 131; 11. (48) Hantzsch, *7*, **61**: 257; 08. (49) Hantzsch and Caldwell, *7*, **58**: 575; 07.

(50) Hantzsch and Caldwell, *7*, **61**: 227; 08. (51) Hantzsch and Meyer, *25*, **43**: 336; 10. (51.5) Hartley and Raikes, *4*, **127**: 524; 25. (52) Hevesy, *9*, **16**: 672; 10. (53) Hodgson, *3*, **18**: 252; 09. (54) Hopfgartner, *57*, **34**: 1313; 13. (55) Jaffé, *8*, **25**: 257; 08. (56) Jaffé, *8*, **28**: 326; 09. (57) Jaffé, *8*, **32**: 148; 10. (58) Johnstone, *292*, **13**: 191; 14. (59) Jones and Lindsay, *11*, **28**: 329; 02.

(60) Jones and McMaster, *11*, **36**: 325; 06. (61) Jones and Mahin, *7*, **69**: 389; 09. (62) Jones and Rouiller, *11*, **36**: 427; 06. (63) Jones and Veazey, *7*, **61**: 641; 08. (64) Julien, *1*, **47**: 1799; 25. (65) Kahlenberg, *7*, **46**: 64; 03. (66) Kahlenberg and Lincoln, *50*, **3**: 12; 99. (67) Kahlenberg and Ruhoff, *50*, **7**: 254; 03. (68) Kahlenberg and Schlundt, *50*, **6**: 447; 02. (69) Kendall and Brakeley, *1*, **43**: 1826; 21.

(70) Kendall and Gross, *1*, **43**: 1426; 21. (71) Kendall and Wright, *1*, **42**: 1776; 20. (72) Keyes and Winninghoff, *1*, **38**: 1178; 16. (73) Klemensiewicz, *165*, **1908**: 485. (74) Koch, *8*, **50**: 482; 93. (75) Koenigsberger and Schilling, *8*, **32**: 179; 10. (76) Koller, *75*, **98 IIa**: 201; 90. (77) Lenher, *1*, **43**: 29; 21. (78) Lenher, *1*, **44**: 1668; 22. (79) Ley, *25*, **38**: 973; 05.

(80) Lincoln, *50*, **3**: 457; 99. (81) Linde, *8*, **56**: 546; 95. (82) McIntosh, *50*, **11**: 306; 07. (83) Malclès, *6*, **16**: 153; 09. (84) Mathews, *50*, **9**: 641; 05. (85) Mittasch, *7*, **46**: 37; 03. (86) Moles and Gómez, *7*, **90**: 594; 15. (87) Monckman, *5*, **46**: 136; 90. (88) Morgan and Lammert, Columbia Univ., *O. 1*, **46**: 881; 24. (89) Moureu, Boutaric and Dufraisse, *42*, **18**: 333; 20.

(90) Mulliken, *11*, **15**: 523; 93. (91) Novák, *3*, **44**: 9; 97. (92) Partington, *4*, **99**: 1937; 11. (93) Patten, *50*, **6**: 554; 02. (94) Pearce, *50*, **19**: 14; 15. (95) Philip and Courtman, *50*, **97**: 1261; 10. (96) Polliack, *Diss.*, Lausanne, 1913. (96.5) Quam and Wilkinson, *1*, **47**: 989; 25. (97) Rabinovich, *93*, **129**: 60; 23. (97.1) Rabinovich, *7*, **119**: 59; 26. (97.2) Rabinovich, *7*, **119**: 70: 26. (97.5) Rabinovich, *7*, **119**: 79; 26. (98) Rimbach and Weitzel, *7*, **79**: 279; 12. (99) Sakhanov and Przheborovskii, *9*, **20**: 39; 14.

(100) Sakhanov and Rabinovich, *53*, **47**: 849; 15. (101) Sammis, *50*, **10**: 593; 06. (102) Schall, *7*, **14**: 701; 94. (103) Schall, *9*, **14**: 397; 08. (104) Schlamp, *7*, **14**: 272; 94. (105) Schlesinger and Calvert, *1*, **33**: 1924; 11. (106) Schlesinger and Coleman, *1*, **38**: 271; 16. (107) Schlesinger and Martin, *1*, **36**: 1589; 14. (108) Schmidt, *7*, **75**: 305; 11. (109) Schmidt and Jones, *11*, **42**: 37; 09.

(110) Schweidler, *8*, **4**: 307; 01. (111) Schweidler, *8*, **5**: 483; 01. (112) Shaw, *50*, **17**: 162; 13. (113) Shinn, *50*, **11**: 537; 07. (114) Steele, McIntosh and Archibald, *62*, **205**: 99; 06. *7*, **55**: 129; 06. (115) Stenquist, *9*, **12**: 860; 06. (116) Svedberg, *20*, **9**: No. 9; 13. (117) Tijmstra, *7*, **49**: 345; 04. (118) Trapesnikow, *242*, **57**: 227; 12. (119) Turner, *11*, **40**: 558; 08.

(120) Vignon, *34*, **148**: 844; 09. (121) Völlmer, *8*, **52**: 328; 94. (122) Walden, *93*, **25**: 209; 00. (123) Walden, *93*, **29**: 371; 02. (124) Walden, *7*, **43**: 385; 03. (125) Walden, *7*, **46**: 103; 03. (126) Walden, *25*, **38**: 345; 05. (127) Walden, *7*, **54**: 129; 06. (128) Walden, *7*, **55**: 683; 06. (129) Walden, *83*, **6**: 71; 10.

(130) Walden, *7*, **73**: 257; 10. (131) Walden, *7*, **78**: 257; 12. (132) Walden and Centnerszwer, *134*, **15**: 17; 01. (133) Walden and Centnerszwer, *7*, **39**: 513; 02. *93*, **30**: 145; 02. (133.5) Walden, Ulich and Laun, *7*, **114**: 275; 24. (134) Walker and Johnson, *4*, **87**: 1592; 05. (134.5) Wartenberg, *13*, **440**: 97; 24. (135) Wigand, *88*, **10**: 495; 08.

ELECTRICAL CONDUCTIVITY OF ELECTROLYTIC CONDUCTORS AT HIGH TEMPERATURES

E. B. Millard

The published values of the conductivities of compressed powders (*p*) are, in general, quite discordant; they are here included by literature reference only. The numerical data refer either to molten materials (*l*) or to solidified melts (*s*); in general, the latter form part of a continuous series including the former, but in some cases solid rods (*r*), either cast or machined from a solidified melt, were used. Some data refer to the undercooled melt; when so stated by the author, they are listed, like other molten materials, under *l*; in all other cases, data for temperatures below the melting point are taken as referring to a solid and are placed under (*s*). For compressed powders of metallic nitrides, *see* (68); for Auer mantle at 1200°C, *see* (66); for recent discussions, *see* (16, 20, 38, 60, 61, 62). Specific conductivity $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; if $n = 0$, $\kappa = C$; t = temperature, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$, where R_0, R_t = resistance of same solid specimen at 0°C, at t, °C.

Im allgemeinen sind die veröffentlichten Werte über die Leitfähigkeit komprimierter Pulver (*p*) ganz widersprechend und werden nur durch die Literaturstellen angegeben. Die numerischen Daten beziehen sich entweder auf geschmolzenes Material (*l*) oder feste Schmelzen (*s*). Im allgemeinen sind letztere Bestandteile einer ununterbrochenen Serie die ersteren einschliessend, aber in manchen Fällen werden feste Stäbe (*r*) verwendet, die entweder gegossen oder aus einer festen Schmelze maschinell hergestellt wurden. Manche Daten beziehen sich auf unterkühlte Schmelzen. Ist dies vom Autor angegeben, so stehen die Daten wie auch die anderen Schmelzen unter *l*. In allen anderen Fällen, bei einer Temperatur unterhalb des Schmelzpunktes werden die Daten als auf den festen Zustand sich beziehend angenommen und stehen dann unter (*s*). Für gepresste Pulver von Metallnitriden, *siehe* (68); für Auerstrümpfe bei 1200°C, *siehe* (66); neuere Diskussionen darüber, *siehe* (16, 20, 38, 60, 61, 62). Spezifische Leitfähigkeit $= \kappa = C \times 10^n$ Ohm^{-1} cm^{-1}; wenn $n = 0$, $\kappa = C$; t = Temperatur, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$, wo R_0, R_t = Widerstand einiger fester Formen bei 0°C bezw. t, °C bedeutet.

En général, les valeurs publiées concernant les conductibilités des poudres comprimées (*p*) sont tout à fait discordantes, aussi ne sont-elles mentionnées ici que par leur références bibliographiques. Les données numériques se rapportent soit à des matières fondues (*l*) soit à des matières fondues solidifiées (*s*); en général ces dernières constituent une partie d'une série continue comprenant les premières, mais dans certains cas il a été fait usage de baguettes solides (*r*) préparées soit par moulage soit par usinage à partir d'une masse fondue solidifiée Certaines données se rapportent à des liquides surfondus; lorsque cet état a été établi par l'auteur, ces données sont inscrites sous *l* comme pour les autres matières fondues; dans tous les autres cas, les données pour des températures au dessous du point de fusion se rapportent à un solide et sont placées sous (*s*). Pour les poudres comprimées des nitrures métalliques, *voir* (68); pour le manchon d'Auer à 1200°C, *voir* (66); pour les discussions récentes, *voir* (16, 20, 38, 60, 61, 62). Conductibilité spécifique $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; si $n = 0$, $\kappa = C$; t = température, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$, où R_0, R_t = résistance de la même éprouvette solide à 0°C, à t, °C.

In generale i valori pubblicati delle conducibilità di polveri compresse (*p*) sono molto discordanti; essi sono qui inclusi solamente come citazione bibliografica. I valori numerici si riferiscono sia a materiali allo stato di fusione (*l*) o a sostanze fuse e lasciate solidificare (*s*); in genere queste ultime sono parte di una serie continua che include anche le precedenti, ma in alcuni casi furono usate bacchette (*r*) o preparate di getto o ricavate al tornio. Alcuni valori si riferiscono a sostanze mantenute liquide allo stato di soprafusione; quando l'affermazione è fatta dall'autore i valori sono inclusi nell'elenco dei materiali allo stato di fusione (*l*); in tutti gli altri casi invece i valori per temperature inferiori al punto di fusione sono supposti riferentisi allo stato solido e sono collocati sotto (*s*). Per le polveri compresse di azoturi metallici, *vedi* (68); per le reticelle Auer a 1200°C, *vedi* (66); per discussioni recenti, *vedi* (16, 20, 38, 60, 61, 62). Conducibilità specifica $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; se $n = 0$, $\kappa = C$; t = temperatura, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0 t$, dove R_0, R_t = resistenza dello stesso campione solido a 0°C e a t, °C.

I. Pure Substances

A-Z-Table; Standard Arrangement

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Unit of $\kappa = 1$ ohm^{-1} cm^{-1}; temperature = t, °C; $\kappa = C \times 10^n$

$TeCl_2$ (64)

t	C
l, $n = -3$	
206	42.0
210	45.8
221	58.9
230	66.8
235	71.2
250	89.3
252	90.4
271	113
271	114
290	133
304	150
305	151

$TeCl_4$ (64)

t	C
l, $n = -3$	
236	114.5
254	136
277	161
290	175
316	203

NH_4NO_3 (23)

l, $n = 0$	
162	2.794
185	2.183
(49)	
172	0.320
187	0.369

NH_4NO_3.—(*Cont'd*)

t	C
202	0.397
213	0.447

$SbCl_3$ (13); *cf.* (37)

l, $n = -3$	
73	0.11

$SbBr_3$ (31)

l, $n = -6$	
99	244
109	261
127	317
158	364
178	405
197	446

SbI_3 (31)

t	C
l, $n = -6$	
169	306
172	334
180	347
184	360
190	372
204	382
218	431
225	440
230	442
239	461
254	482
266	491
307	586
378	683

$BiCl_3$ (64)

l, $n = -3$	
266	442
295	481

$BiCl_3$.—(*Cont'd*)

t	C
315	506
335	533
350	555

C, *p* (53)

$(CH_3)_2NH.HNO_3$*

74	178
78	187
89	210
98	234
112	259

$C_2H_5NH_2.HCl$*

100	50.5
110	60.1
122	71.6
130	79.3

*l, $n = -3$ (65).
†l, $n = -4$ (65).

$C_2H_5NH_2.HNO_3$*

t	C
25	23.0
43	39.8
53	50.2
70	67.7
78	75.2
90	87.9
101	98.7

$(C_2H_5)_2NH.HNO_3$*

100	75.9
105	80.5
116	89.1
125	96.5

$C_6H_5N(CH_3)_2.HBr$†

70	8.97
88	33.2
100	49.9
110	64.3
119	764

$ZrSiO_4$, p (44)

SnS (30)

r, $\alpha = -6.62$

$15° < t < 920°$

$\rho_0 = 1071$ ohm cm

PbO_2, p (55); *cf.* (21)

$PbCl_2$ (43, 49)

t	C
l, $n = 0$	
500	1.33
525	1.57
550	1.70
575	1.84
600	1.95
650	2.25
700	2.5

p (36)

$PbBr_2$ (43)

l, $n = -3$	
372	540
382	612
392	648
402	684
412	720
422	756
432	790
442	824
452	857
462	890
472	922
482	953
492	984

p (36)

PbS (30)

r, $\alpha = +5.01$

$-25° < t < 900°$

$\rho_0 = 0.000298$ ohm cm

$ThCl_4$ (64)

l, $n = 0$	
814	0.61
843	0.67
866	0.71
889	0.76
922	0.78

TlCl (58)

s, $n = -3$	
250	0.05
300	0.24
350	0.90
400	3.70
421	6.11
l, $n = 0$	
431	1.090
450	1.170
500	1.332
550	1.532
600	1.700

TlBr (58)

s, $n = -3$	
250	0.04
300	0.12
350	0.55
400	1.6
446.5	5.15

TlBr.—(*Cont'd*)

t	C
l, $n = 0$	
460	0.807
500	0.905
550	1.024
600	1.127

TlI (58)

s, $n = -3$	
250	0.10
300	0.39
350	1.02
400	2.73
429	4.80
l, $n = 0$	
439	0.528
450	0.551
500	0.651
550	0.747
600	0.840

s (24)

Tl_2S, l, s (46)

$ZnCl_2$ (15)

s, $n = -3$	
319	0.2
324	1.4
331	2.1
336	2.4
337	2.5
340	2.8
341	2.9
342	3.05
344	3.32
364	6.5
367	6.76
373	8.34
l, $n = -1$; *cf.* (23)	
373	0.083
402	0.153
460	0.509
500	0.838
542	1.43
581	2.10
612	2.55
650	3.12

$Zn(NO_3)_2.6H_2O$, s (34)

$CdCl_2$ (15)

s, $n = -2$	
534	0.07
543	0.4
554	1.2
l, $n = 0$	
576	1.925
581	1.92
591	1.92
595	1.95
597	1.97
623	2.01
635	2.06
636	2.04
660	2.14
668	2.12
692	2.17
721	2.23

$CdCl_2$.—(*Cont'd*)

t	C
750	2.32
755	2.30
795	2.37
801	2.37

$HgCl_2$ (31)

l, $n = -3$	
276	0.77

s (31)

$HgBr_2$ (31)

l, $n = -3$	
132	1.46

s (31)

HgI_2 (31)

l, $n = -3$	
253	11.76
260	8.48
263	7.94
288	7.14
298	6.94
320	6.62

s (31)

CuCl (15)

s, $n = -3$	
349	17
358	42
359	28
368	65
370	36
371	86
375	46
$n = 0$	
379	0.11
385	0.08
387	0.14
395	0.13
398	0.14
407	0.33
409	0.22
426	2.93
l, $n = 0$	
430	3.27
443	3.28
443	3.29
492	3.44
533	3.49
577	3.63

s (24)

CuBr, s (24)

CuI, s (24)

Cu_2S (19)

l, $n = 0$	
1120	76.22
1150	78.69
1200	83.30
1250	88.34
1300	94.10
1350	100.68
1400	108.25
1450	117.07
1500	127.17
1550	139.51

p (45, 59)

$Cu(NO_3)_2.6H_2O$, s (34)

AgCl (42, 58)

t	C
s, $n = -3$	
250	0.30
300	1.5
350	6.5
400	26
450	112
l, $n = 0$	
500	4.25*
550	4.35
600	4.45
650	4.55
700	4.65
750	4.8
800	4.9

p, s (10, 24, 40)

* ± 0.05.

$AgClO_3$ (27)

l, $n = -3$	
200	321.9
210	352.7
215	367.6
220	382.9
230	413.4
240	444.4
250	474.3

AgBr (42, 58)

s, $n = -3$	
150	0.08
200	0.75
250	4.4
300	23
$n = 0$	
350	0.11
400	0.53
l, $n = 0$	
450	3.0*
500	3.1
550	3.2
600	3.3
650	3.3
700	3.4
750	3.5
800	3.6

p, s (10, 24, 40)

* ± 0.01.

AgI (2, 42, 58)

s, $n = -3$	
142.4	0.333
145.0	*
$n = 0$	
146.5	1.308
150	1.33
200	1.57
250	1.78
300	1.97
350	2.14
400	2.28
450	2.41
500	2.52
550	2.64

AgI.—(*Cont'd*)

t	C
l, $n = 0$	
550	2.3†
600	2.35
650	2.4
700	2.45
750	2.5
800	2.6

s (24)

* Transition temp.

† ± 0.1.

Ag_2S, p (45, 59)

$AgNO_3$ (27, 49)

l, $n = 0$	
200	0.65
225	0.75
250	0.85
275	0.95
300	1.06
325	1.16
350	1.27

s (48)

$Mn(NO_3)_2.6H_2O$, s (34)

FeS* (30, 39)

r, $\alpha = 7.98$

$0° < t < 100°$

$\rho_0 = 0.1114$ ohm cm

* ρ is greater for heating than for cooling.

FeS_2 (8)

r, $\rho_{20} = 1.513$ ohm cm

$FeO.TiO_2$ (39)

Ilmenite

$Co(NO_3)_2.6H_2O$, s (34)

$Ni(NO_3)_2.6H_2O$, s (34)

$MoCl_5$ (64)

l, $n = -6$	
216	1.8
234	4.1
258	7.5

WCl_5 (64); *cf.* (13)

l, $n = -6$	
250	0.67
255	0.84
260	0.97
265	1.09
270	1.22
275	1.35
280	1.49
285	1.62
290	1.70
295	1.77
300	1.84

WCl_6 (64); *cf.* (13)

t	C
l, $n = -6$	
280	1.98
285	2.13
290	2.28
295	2.44
300	2.60
305	2.85
310	3.11
315	3.38
320	4.05
325	5.13
330	6.94

UCl_4 (64)

l, $n = 0$	
570	0.34
598	0.42
620	0.48

$CbCl_5$ (17)

l, $n = -6$	
228*	0.22

* 220 to 235°.

$TaCl_5$ (17)

l, $n = -6$	
235*	0.3

* 230 to 240°.

$AlBr_3$ (18)

l, $n = -6$	
195	0.09
210	0.12
225	0.15
232	0.16
243	0.18
250	0.19
260	0.20
266	0.24

AlI_3 (18)

l, $n = -6$	
209	2.6
218	3.3
226	3.9
238	4.7
246	5.2
260	6.3
265	6.8
270	7.4

$ScCl_3$ (14); *cf.* (64)

l, $n = 0$	
959	0.51
969	0.55
981	0.57
991	0.59

Yt_2O_3, p (44)

$LaCl_3$ (64)

l, $n = 0$	
950	1.30
975	1.36
1000	1.42
1025	1.49
1050	1.56
1075	1.63
1100	1.70
1135	1.77

$PrCl_3$ (64)

t	C
l, $n = 0$	
824	0.82
849	0.89
875	0.97
902	1.06
935	1.16
965	1.26

$NdCl_3$ (64)

l, $n = 0$	
775	0.63
807	0.71
827	0.765
847	0.81
873	0.88
900	0.945

$BeCl_2$ (64)

l, $n = -3$	
451	3.19
460	5.72
472	8.68

MgO (26)

r, $n = -6$	
800	0.0_1
900	0.1_0
1000	0.2_0
1050	0.3_4
1100	1.0
1150	2.6
p (44)	

$MgCl_2$ (15)

l, $n = 0$	
729	1.05
743	1.08
772	1.105
774	1.13
822	1.23
830	1.21
884	1.32
909	1.39
941	1.45
959	1.455
997	1.53
1013	1.58

$CaCl_2$ (1, 2)

l, $n = 0$	
800	1.9
850	2.1
900	2.3
950	2.5
1000	2.7
1050	2.8

$SrCl_2$ (1)

l, $n = 0$	
900	1.98
950	2.14
1000	2.29
1050	2.43
1100	2.56

$BaCl_2$ (1)

t	C
l, $n = 0$	
900	(1.71)
950	1.89
1000	2.05
1050	2.19
1100	2.31
s (63)	

LiCl (15)

s, $n = 0$	
577	0.15
592	0.16
595	0.25
l, $n = 0$	
620	5.865
631	5.94
681	6.14
702	6.21
746	6.40
762	6.44
786	6.53
801	6.585

$LiNO_3$ (27, 33)

l, $n = 0$	
250	0.80
275	0.92
300	1.06
325	1.19
350	1.33
375	1.46
400	1.59
425	1.72
450	1.86
p (9)	

NaOH (4, 22); *cf.* (5)

l, $n = 0$	
320	2.12
350	2.38
400	2.82
450	3.27

NaF, s (47)

NaCl (49)

l, $n = 0$	
720	2.87
740	3.22
750	3.40
770	3.77
780	4.09
(1)	
850	3.50
900	3.66
950	3.82
p, s (10, 35, 47, 57, 63)	

NaBr (49)

l, $n = 0$	
710	2.40
750	2.85
760	2.95
780	3.27
800	3.52

NaBr.—(*Cont'd*)

t	C
(2)	
800	3.06
850	3.23
900	3.30
s (47, 57)	

NaI (49)

l, $n = 0$	
615	2.00
650	2.30
670	2.43
680	2.59
700	2.72
s (47)	

Na_2SO_4 (1)

l, $n = 0$	
900	2.23
950	2.37
1000	2.50
1050	2.64
1100	2.77
s (63)	

$Na_2S_2O_3$ (41)

l, $n = -3$	
0	6.9
5	10.8
10	15.9
15	22.4
20	30.4
25	39.3
30	49.7
35	62.0
40	75.8
45	90.8
50	106.1
55	123
60	141
65	160
70	180
75	201
80	222
85	244

$NaNO_3$ (33, 43)

l, $n = 0$	
300	0.95
325	1.05
350	1.15
375	1.25
400	1.35
425	1.45
450	1.56
475	1.66
500	1.76
p, s (9, 57)	

$NaNH_2$ (67)

l, $n = 0$	
210	0.593

$NaPO_3$ (2)

l, $n = 0$	
600	0.30
650	0.425
700	0.55

$NaPO_3$.—(*Cont'd*)

t	C
750	0.675
800	0.80
850	0.925
900	1.05
950	1.175
1000	1.30
1050	1.42
1100	1.54

Na_2CO_3 (1)

l, $n = 0$	
850	2.92
900	3.10

$NaC_2H_3O_2$, (41)
Acetate

l, $n = -3$	
0	3.95
5	6.2
10	9.3
15	13.2
20	18.0
25	23.5
30	30.5
35	38.5
40	46.7
45	56.0
50	66.0
55	77.0
60	89.0
65	101.0
70	113.5
75	126
80	139
85	152
90	166

$NaC_{16}H_{31}O_2$, Palmitate (11)

l, $n = -6$	
170	36.80
174	44.16
178	45.99
182	47.99
186	53.84
190	58.09
194	60.64
198	76.12

$NaC_{18}H_{31}O_2$ (12)
Linoleate

$NaC_{18}H_{33}O_2$ (12)
Oleate

$NaC_{18}H_{35}O_2$ (11)
Stearate

l, $n = -6$	
158	29.84
162	38.06
166	50.18
170	55.75
174	59.99
178	61.32

Na_2MoO_4 (33)

t	C
l, $n = 0$	
843	1.411
905.5	1.522
924.5	1.571
977	1.679
1026	1.775
1064.5	1.843
1122.5	1.940
1173	2.016
1217	2.093
1267.5	2.170
1306	2.232
1364	2.330
1408	2.403

Na_2WO_4 (33)

l, $n = 0$	
752.5	1.091
800	1.192
958	1.519
996.6	1.598
1066	1.718
1161	1.893
1209	1.990
1260	2.083
1361.5	2.250
1412	2.335
1501	2.453

KOH, l (5)

KF (33)

l, $n = 0$	
863.0	2.948
881.1	3.114
901.3	3.270
905.4	3.299
916.3	3.418
968.3	3.889
975.0	3.952

KCl (1, 2, 33, 49)

l, $n = 0$	
775	2.23
800	2.34
825	2.44
850	2.55
875	2.65
900	2.76
925	2.86
950	2.97
975	3.07
p, s (9, 10, 40, 57)	

$KClO_3$ (23)

l, $n = 0$	
359	4.19

KBr (2, 33); *cf.* (49)

l, $n = 0$	
750	1.61
775	1.67
800	1.72
825	1.79
850	1.84
(900)	(1.95)
(950)	(2.08)
s (57, 63)	

KI (2, 33, 49)

t	C
l, $n = 0$	
600	1.04
650	1.15
700	1.24
750	1.35
800	1.45

K_2SO_4 (1)

l, $n = 0$	
1100	1.84
1150	1.94

KNO_3 (7, 23, 33, 43)

l, $n = -3$	
(250)	(36_0)
(300)	(51_0)
330	602
340	634
350	664
360	694
370	724
380	754
390	784
400	816
410	848
420	876
440	937
460	996
480	1055
500	1116

KNH_2 (67)

l, $n = -3$	
340	389

K_2CO_3 (1)

l, $n = 0$	
900	1.95
950	2.12
1000	2.26

$KC_{16}H_{31}O_2$ (11)
Palmitate

l, $n = -6$	
182	55.75
186	64.94
190	67.32
194	69.85
198	72.63
202	73.58
207	75.09

$KC_{18}H_{31}O_2$ (12)
Linoleate

$KC_{18}H_{33}O_2$ (11)
Oleate

l, $n = -6$	
200	45.05
204	50.18
208	52.57
212	55.20
218	58.70
222	59.34

$KC_{18}H_{35}O_2$ [11]
Stearate

t	C
l, $n = -6$	
224	110.4
226	122.7
228	138.0
230	169.8
232	184.0
234	256.6
237	315.4
239	368.0

K_2CrO_4, p [10]

$K_2Cr_2O_7$ [43]

l, $n = -3$	
397	196
407	220
417	238
427	256
437	275
447	293
457	311
467	329
477	347
487	366
497	384
507	402

RbCl [15]

t	C
l, $n = 0$	
733	1.49
765	1.58
769	1.59
780	1.62
819	1.70
839	1.74
873	1.81
915	1.87

$RbNO_3$ [33]

l, $n = -3$	
318.8	439
341.3	490
351.3	511
357.0	524
376.0	569
379.4	573
409.0	636
422.8	666
435.9	692
448.6	720
468.7	755
493	804

CsCl [15]

t	C
l, $n = 0$	
660	1.14
685	1.18
711	1.26
722	1.27
751	1.34
775	1.39
809	1.44
831	1.48

$CsNO_3$ [33]

l, $n = -3$	
446.6	594
472.7	634
490.2	656
498.0	670
510.1	685
525.3	705
541.7	723
556.3	744

II. Binary Mixtures

A-B-Table; Standard Arrangement

v. Vol. III, p. viii

M = mole, M % = mole %, Wt. % = weight %, m_A = mass of A, l = molten, p = compressed powder, r = solid rod, s solidified melt, κ = specific conductivity. Unit of κ = 1 ohm^{-1} cm^{-1}; t = temperature, °C; $\kappa = C \times 10^n$.

I

B = HgI_2 [31]

t	C
$m_A = 10\% \, m_B$	
s, $n = -3$	
110	0.046
208	0.139
226	1.18
233	3.64
$m_A = m_B$	
s, $n = -3$	
165	0.14
206	0.645
227	1.05

$SbCl_3$
B = NH_4Cl, TlCl, RbCl, or KCl
l [37]

$SbBr_3$
B = $AlBr_3$

Wt. % A	C
t = 99.5°C [32]	
l, $n = -6$	
1.09	0.06
3.60	5.31
5.68	85.43
6.37	137.7
7.31	267.4

B = $AlBr_3$.— (*Continued*)

Wt. % A	C
8.75	483.5
9.85	714.8
$n = -3$	
14.15	1.647
15.27	1.924
19.33	2.884
22.31	3.601
25.58	4.267
29.91	5.348
35.10	6.331
40.00	7.303
45.59	8.248
47.98	8.607
49.52	8.982
55.28	9.894
60.19	11.646
65.29	13.212

t	C
Wt. % A = 15.27	
l, $n = -3$	
99.5	1.924
110.3	2.173
120.3	2.363
130.5	2.492
140.3	2.542
150.0	2.515
160.6	2.411

B = $AlBr_3$.— (*Continued*)

t	C
170.5	2.248
180.0	2.050
190.1	1.851
Wt. % A = 50.35	
99.5	9.135
110.3	11.62
120.3	13.16
130.5	15.35
140.3	17.58
150.0	20.11
160.6	23.22
170.5	25.43
180.0	27.70
190.1	29.58

$SnCl_2$
B = $PbCl_2$
p [9]

PbO_2
B = MnO_2
s [21]

$PbCl_2$
B = $PbBr_2$

M % B	C, 200°	C, 250°
r [50], $n = -6$		
0	50	140
15	34	90
30	22	75
40	16	54
50	12	40
60	17	67
70	38	102
85	46	223
100	81	274

M % B	C
t = 300°, $n = -3$	
0	0.60
15	0.40
30	0.25
40	0.23
50	0.21
60	0.24
70	0.34
85	0.58
100	0.86

Wt. % A	C
l [51], $n = 0$	
t = 500°C	
0.00	1.030
7.76	1.059
20.15	1.108
43.09	1.201
69.44	1.310
87.21	1.400
100.00	1.472

TlCl
B = $CdCl_2$

Wt. % A	C
l [51], $n = 0$	
t = 600°C	
0	1.971
20	1.808
35	1.781
40	1.665
50	1.566
53.7	1.522
60	1.520
75	1.564
85	1.610
90	1.664
100	1.702
t = 700°C	
0	2.101
20	1.990
35	1.950
40	1.857
50	1.789
53.7	1.718
60	1.720
75	1.760
85	1.818
90	1.860
100	1.951

B = AgCl

M % A	C
r [50], $n = -6$	
t = 200°C	
0	50
15	65
30	86
40	104
50	92
60	75
70	65
80	32
100	13

Wt. % A	C
l [51], $n = 0$	
t = 500°C	
0.00	3.653
22.77	2.925
42.00	2.260
63.00	1.771
79.43	1.470
100.00	1.215

$TlNO_3$*
B = $AgNO_3$*

Wt. % B	C
l [51], $n = 0$	
t = 250°C	
0	0.436
10	0.465
25	0.512
50	0.580
75	0.695
100	0.812

* In original, table headed TlCl and AgCl; column headed $AgNO_3$; as it is stated that Wt. % A = 50 is equivalent to M % A = 61.02, both salts were probably nitrates.

Cd*
B = $CdCl_2$

M % A	C
l [6], $n = 0$	
t = 580°C	
0	1.907
2.5	1.898
5.0	1.884
7.5	1.867
10	1.845
t = 600°C	
0	1.968
2.5	1.959
5.0	1.945
7.5	1.928
10	1.906
t = 620°C	
0	2.023
2.5	2.016

B = $CdCl_2$.— (*Continued*)

M % A	C
5.0	2.004
7.5	1.989
10	1.969

* Values for "commercial" products, 3.4, 7.2, and 11.5 M % A, at 10° intervals from 580 to 700°C are also given.

$CdCl_2$
B = KCl

Wt. % A	C
l [51], $n = 0$	
t = 800°C	
0	2.301
10	2.163
20	2.041
30	1.911
35	1.852
50	1.735
55	1.785
60	1.662
65	1.703
70	1.771
75	1.841
80	1.929
90	2.110
100	2.250
t = 900°C	
0	2.522
10	2.315
20	2.160
30	2.061
35	2.000
50	1.882
55	1.800
60	1.776
65	1.800
70	1.868
75	1.940
80	2.090
90	2.151
100	2.401

$HgBr_2$
B = $AlBr_3$

Wt. % A	C
l [32], $n = -6$	
t = 99.50°C	
1.38	0.121
3.06	0.439
5.52	8.851
8.14	148.94
10.48	601.74
$n = -3$	
14.26	1.9785
18.34	4.1683
21.11	5.8380
27.15	9.7988

B = $AlBr_3$.—(*Cont'd*)

t	C
$n = -6$	
Wt. % A = 7.81	
99.5	120.6
110.3	127.1
120.3	135.9
130.5	133.0
140.3	128.6
150.0	121.6
160.6	107.5
170.5	96.2
180.0	84.7
190.1	71.4
$n = -3$	
Wt. % A = 14.38	
99.5	2.051
110.3	2.369
120.3	2.583
130.5	2.772
140.3	2.892
150.0	2.943
160.6	2.867
170.5	2.786
180.0	2.668
190.1	2.454
Wt. % A = 21.08	
99.5	5.814
110.3	7.002
120.3	8.061
130.5	9.059
140.3	10.01
150.0	10.73
160.6	11.32
170.5	11.77
180.0	11.94
190.1	11.96

CuO

B = MnO_2, *s* (21)

AgCl

B = AgBr

M % B	C
s (50), $n = -3$	
t = 200°C	
0	0.05
10	0.08
30	0.13
40	0.16
50	0.20
60	0.23
70	0.32
80	0.38
90	0.42
100	0.46
t = 250°C	
0	0.20
10	0.35
30	0.66
40	0.92
50	1.26
60	1.56
70	2.10
80	2.31
90	2.40
100	2.60

B = AgBr.—(*Continued*)

M % B	C
t = 300°C	
0	1.09
10	1.68
30	3.50
40	5.52
50	7.01
60	8.17
70	10.8
80	11.9
90	12.9
100	14.0
t = 350°C	
0	5.20
10	5.49
30	16.8
40	22.0
50	32.0
60	37.0
70	42.5
80	52.0
90	58.5
100	64.2
t = 400°C	
0	24.0
10	31.8
30	57.0
40	75.3
50	120
60	140
70	164
80	235
90	272
100	304

Wt. % A	C
t = 500°C	
l (51), $n = 0$	
0.00	2.924
24.65	3.130
43.00	3.246
64.00	3.409
100.00	3.653

B = KCl, *p* (10)

MnO_2

B = KBr, *s* (21)

$AlBr_3$

B = KBr

Wt. % B	C
t = 99.5°C (32)	
l, $n = -3$	
11.02	16.33
12.65	18.53
13.07	19.14
15.44	21.95
16.84	23.62
18.46	25.46
t	C
Wt. % B = 13.07	
99.5	19.14
110.3	23.60
120.3	27.02
130.5	29.14

B = KBr.—(*Cont'd*)

t	C
140.3	31.85
150.0	34.74
160.6	36.75
170.5	39.33
180.0	43.02
190.1	45.47

$CaCl_2$

B = NaCl

Wt. % B	C
l (51), $n = 0$	
t = 850°C	
0.00	2.220
2.51	2.191
5.14	2.190
10.00	2.235
20.00	2.307
35.50	2.404
40.00	2.452
42.26	2.520
50.00	2.635
60.00	2.830
75.00	3.016
80.00	3.260
100.00	3.575
t = 950°C	
0	2.580
10	2.375
40	2.576
50	2.820
75	3.230
100	3.890

B = KCl

l (51), $n = 0$	
t = 800°C	
0	2.006
10	1.772
20	1.620
25	1.554
30	1.501
35	1.477
40	1.478
45	1.480
50	1.492
60	1.550
70	1.708
80	1.951
100	2.301
t = 900°C	
0	2.405
10	2.090
20	1.893
25	1.835
30	1.730
35	1.699
40	1.702
45	1.700
50	1.766
60	1.852
70	1.973
80	2.195
100	2.522

LiCl

B = KCl

p (9)

$LiNO_3$

B = $NaNO_3$

p (9)

NaCl

B = KCl

Wt. % A	C
l (51), $n = 0$	
t = 850°C	
0	2.420
5	2.441
25	2.559
50	2.862
65	3.022
75	3.159
90	3.448
100	3.575

p (10)

$NaNO_3$

B = KNO_3

t	C
l (27), $n = 0$	
$4M_A + 1M_B$	
321.6	0.9119
399.1	1.224
454.1	1.401

B = KNO_3.—(*Continued*)

t	C
$1M_A + 1M_B$	
320	0.7475
330	0.7890
340	0.8293
350	0.8680
360	0.9050
370	0.9410
380	0.9768
390	1.011
400	1.045
410	1.078
420	1.111
430	1.143
440	1.174
450	1.205
$1M_A + 4M_B$	
320	0.6318
330	0.6668
340	0.7015
350	0.7358
360	0.7705
370	0.8055
380	0.8393
390	0.8730
400	0.9053
410	0.9370
420	0.9678
430	0.9983
440	1.028
450	1.059

B = KNO_3.—(*Continued*)

Wt. % A	C
l (51), $n = 0$	
t = 350°C	
0.00	0.670
17.38	0.740
45.16	0.872
71.10	1.030
100.00	1.170
t = 400°C	
0.00	0.818
17.38	0.900
45.16	1.030
71.10	1.221
100.00	1.371

See also (23)

KCl

B = KBr

s (57)

B = K_2CrO_4

p (10)

Permutite Ag-, and Na-

s (28)

Permutite Ag-Na, and Ag-K

s (29)

Cryolite mixtures

l (3)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Arndt, *9*, **12**: 337; 06. (2) Arndt and Gessler, *9*, **14**: 662; 08. (3) Arndt and Kalass, *9*, **30**: 12; 24. (4) Arndt and Ploetz, *7*, **110**: 237; 24. (5) Arndt and Ploetz, *7*, **121**: 439; 26. (6) Aten, *7*, **73**: 578; 10. (7) Aten, *7*, **78**: 1; 11. (8) van Aubel, *34*, **135**: 456, 734; 02. (9) Benrath and Tesche, *7*, **96**: 474; 20.

(10) Benrath and Wainoff, *7*, **77**: 257; 11. (11) Bhatnagar and Prasad, *55*, **34**: 193; 24. (12) Bhatnagar, Prasad and Singh, *55*, **38**: 218; 26. (13) Biltz, *7*, **100**: 52; 22. (14) Biltz and Klemm, *93*, **131**: 22; 23. (15) Biltz and Klemm, *7*, **110**: 318; 24. (16) Biltz and Klemm, *93*, **152**: 267; 26. (17) Biltz and Voigt, *93*, **120**: 71; 22. (18) Biltz and Voigt, *93*, **126**: 39; 23. (19) Bornemann and von Rauschenplat, *192*, **9**: 473, 505; 12.

(20) Fischer, *9*, **32**: 136; 26. (21) Fischer, *9*, **32**: 538; 26. (22) Fleck and Wallace, *83*, **16**: 346; 21. (23) Foussereau, *51*, **4**: 189; 85. (24) Friederich and Meyer, *9*, **32**: 566; 26. (25) Ghosh, *4*, **117**: 823; 20. (26) Goodwin and Mailey, *2*, **23**: 22; 06. (27) Goodwin and Mailey, *2*, **26**: 28; 08. (28) Günther-Schulze, *7*, **89**: 168; 15. (29) Günther-Schulze, *9*, **25**: 330; 19.

(30) Guinchant, *34*, **134**: 1224; 02. (31) Hevesy, *137*, **3**: No. 13; 21. (32) Izbekov and Plotnikov, *53*, **43**: 18; 11. (33) Jaeger and Kapma, *93*, **113**: 27; 20. (34) Jakubsohn and Rabinovich, *7*, **116**: 359; 25. (35) Joffé and Zechnowitzer, *208*, **6**: 36; 26. (36) Ketzer, *9*, **26**: 77; 20. (37) Klemensiewicz, *7*, **113**: 28; 24. (38) Klemm and Biltz, *93*, **152**: 225; 26. (39) Koenigsberger and Schilling, *8*, **32**: 179; 10.

(40) Kohlrausch, *8*, **17**: 642; 82. (41) Levi, *24*, **74**: 1167; 15. (42) Lorenz and Höchberg, *93*, **94**: 305; 16. (43) Lorenz and Kalmus, *7*, **59**: 17; 07. (44) Nernst and Reynolds, *188*, **1900**: 328. (45) Ourasov, *53*, **51**: 311; 19. (46) Pélabon, *34*, **173**: 142; 21. (47) Phipps, Lansing and Cooke, *1*, **48**: 112; 26. (48) Piatti, *59*, **3**: 405; 26. (49) Poincaré, *6*, **21**: 289; 90.

(50) Sandonnini, *22*, **24 I**: 842; 15. (51) Sandonnini, *36*, **50 I**: 289; 20. (52) Schulze, *9*, **19**: 122; 13. (53) Streintz, *8*, **3**: 1; 00. (54) Streintz, *8*, **9**: 854; 02. (55) Streintz, *9*, **10**: 414; 04. (56) Streintz, *8*, **44**: 545; 14. (57) Tammann and Veszi, *93*, **150**: 355; 26. (58) Tubandt, *in B13*, p. 446. (59) Tubandt, Eggert and Schibbe, *93*, **117**: 1; 21.

(60) Vaillant, *51*, **3**: 87; 22. (61) Vaillant, *51*, **5**: 84; 24. (62) Vaillant, *34*, **179**: 530; 24. (63) Vaillant, *34*, **182**: 1335; 26. (64) Voigt and Biltz, *93*, **133**: 277; 24. (65) Walden, *134*, **8**: 405; 14. (66) Weissenberger, *in* Koenigsberger, *63*, **14**: 643; 13. (67) Wöhler and Stang-Lund, *9*, **24**: 261; 18. (68) Zhukov, *53*, **42**: 40; 10.

THE ELECTRICAL CONDUCTIVITY AND THE IONIZATION-PRODUCT OF H_2O

NIELS BJERRUM

ELECTRICAL CONDUCTIVITY

Ice (3)					
	t, °C	0	−4	−10	−19
	$10^{10}\kappa$, (mho)	280	23	11	2.6

Water.—The specific conductance of pure liquid H_2O (mho) at any temperature may be computed from the following equation using the appropriate value of p_w obtained from the tables which follow:

$$\log_{10}\kappa = [\log_{10}(\Lambda \times d) - 3 - \tfrac{1}{2}p_w],$$

where d is the density of water in g/ml and $\Lambda(=\Lambda_{H^+}+\Lambda_{OH^-})$ is the equivalent conductance for $H^+ + OH^-$, all at t, °C.

Example at 18°: $\log_{10}\kappa = \log_{10}(315.2+174)(0.9986) - 3 - 7.11 = 7.42$. $\kappa = 0.038 \times 10^{-6}$ mho, which may be compared with the directly measured value 0.042×10^{-6} for Kohlrausch and Heydweiller's "best" water.

IONIZATION PRODUCT

$K_w = [H^+]\,[OH^-]$; $[H^+]$ and $[OH^-]$ are the concentrations in moles per 1000 grams of water.

VALUES OF THE IONIZATION-EXPONENT OF WATER: $-\log_{10}K_w = p_w$*

t, °C	Calculated from the conductance of the purest water†	Calculated from the hydrolysis of salts of weak acids and weak bases			
		Ionization of the salt calculated from conductance		Activity-coefficient of the ions, f, calculated by means of the formula: $-\log_{10} f = 0.3.\sqrt[3]{C_i}$	
	(5, 6)	(9)	(4)	(9)	(4)
0	14.93		15.05		14.99
10	14.52	14.51		14.47	
15		14.34		14.30	
18	14.22		14.34		14.27
25	13.98	13.98	14.09	13.94	14.03
40		13.53		13.49	
50	13.25	13.29		13.25	
		(11)‡	(14)‡		
100		12.28			
156		11.57			
218			11.19		
306			11.46		

* pH in pure liquid $H_2O = \tfrac{1}{2}p_w - \log_{10} d$.

† The values in the table are calculated from the formula of Heydweiller (2): $-\log_{10}K_w = 6099.6/(273+t) + 24.25\log_{10}(273+t) - 66.4678$.

‡ Recomputed to mole/1000 gram water.

Calculated from the potential of cells with hydrogen electrodes in acid and alkaline solutions

t, °C	Ion-concentrations calculated by means of conductance measurements				Activity-coefficients of the ions calculated on thermodynamical basis	
	(8)	(12)	(10)	(13)	(7)*	(1)†
0	14.87				14.945	14.926
18	14.15		14.13	14.14	14.239	14.222
25	13.92	13.91	13.89		13.998	13.980
30	13.76		13.72			
37			13.50		13.626	13.590
40	13.41		13.42			
50	13.06				13.273	
60	12.90					
70	12.67					
80	12.46					
90	12.37					
100					12.29	

* The potential measurements are made at 25°, and from the value of K_w at 25° the values at the other temperatures are calculated, using for the heat of neutralization $29\,210 - 53T$, which gives for K_w the following formula: $-\log_{10}K_w = 6384.7/(273.1+t) + 26.676\log_{10}(273.1+t) - 73.424$

† Debye-Hückel square-root formula used as the limiting law for $C = 0$.

Best values

t, °C	p_w	t, °C	p_w
0	14.93	50	13.26
5	14.72	60	13.03
10	14.53	70	12.82
15	14.34	80	12.63
18	14.23	90	12.45
20	14.16	100	12.29
25	13.99	150	11.63
30	13.83	200	11.26
35	13.67	250	11.17
37	13.61	300	11.40
40	13.52	306	11.46
45	13.39		

Computed by means of the values in the foregoing tables. Below 100° the values from potential and hydrolysis determinations based upon dissociation computed from conductance data are not used. Of the other values the greatest weight is given to the potential determinations.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bjerrum and Unmack, *137*, **9**: No. 1; 29. (2) Heydweiller, *8*, **28**: 503; 09. (3) Johnstone, *292*, **13**: 126; 12. (4) Kanolt, *152*, **No. 63**: 285; 07. (5) Kohlrausch and Heydweiller, *8*, **53**: 209; 94. (6) Kohlrausch and Heydweiller, *7*, **14**: 317; 94. (7) Lewis and Randall, *Thermodynamics and the free energy of chemical substances*. New York, McGraw-Hill, 1923. (8) Lorenz and Böhi, *7*, **66**: 733; 09. (9) Lundén, *42*, **5**: 574; 07. (10) Michaelis, *Die Wasserstoffionenkonzentration*. Berlin, Springer, 1914. (11) Noyes and Kato, *152*, **No. 63**: 153; 07. (12) Poma and Tanzi, *7*, **79**: 55; 12. (13) Sörensen, *205*, **21**: 131; 09. (14) Sosman, *152*, **No. 63**: 193; 07.

ELECTRICAL RESISTIVITY OF (1) SINGLE CRYSTALS, (2) SOLID POOR CONDUCTORS (EXCEPT SALTS), (3) MIXTURES OF RARE EARTH OXIDES AND (4) LIQUID MIXTURES SUITABLE FOR HIGH RESISTANCES

G. M. J. MACKAY

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Minerals and other single crystals.
Nernst and Auer mixtures containing rare earth oxides.
Mixed liquids suitable for high resistances.
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MATIÈRES

Substances pures.
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Mélanges liquides convenant pour hautes résistances.
Effet de la pression.
Résistance de surface.
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INHALTSVERZEICHNIS

Reine Stoffe.
Mineralien und andere Einzelkristalle.
Nernst- und Auer- Mischungen, enthaltend Oxyde seltener Erden.
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Salts (excepting conduction in single crystals), pure liquids, electrolytic solutions, and industrial materials, are specifically excluded from this section of the Tables; *v.* Index at end of Vol. VII.

In view of the large effect produced by traces of impurities, by variations in absorption, polarization, surface leakage, etc., the values given should be regarded, in most cases, as mere approximations. The resistivity of specimens of minerals from different localities may differ by several hundred fold.

For high frequency alternating current resistance, *see* (16, 17); for Hall effect, *see* (24, 27); for mixtures of oxides, *see* Table 3 and (42).

TABLE 1.—ELECTRICAL RESISTIVITY (ρ) OF POOR CONDUCTORS: PURE SUBSTANCES

$\rho = A \times 10^n$; s = solid, l = liquid; $\bar{5}$ denotes -5; if $A = 7.8$ and $n = \bar{5}$, then $\rho = 7.8 \times 10^{-5}$. (In certain cases ρ_t can be computed by means of one of the following formulae: $\rho_t = \rho_0\{1 + at(10)^{-3}\}$; $\rho_t = \rho_0\{1 + \alpha t(10)^{-3} \pm \beta t^2(10)^{-6}\}$ e^{-qt/TT_0}, $T[T_0]$ = absolute temperature corresponding to t[0°C], $T_0 = 273.1$°K; if $t < 0$°C use the minus sign before the β. Values of coefficients are given after numerical data.) Unit of $\rho = 1$ ohm cm = 0.3937 ohm in. Centigrade temperatures, °C.

Elementary Substances

B, Cast* (47)

t	A	n
0	1.8	6
600	1 *ca.*	0

Br (35)

−18.5	1.25	11

C, Diamond (44)

15	4.7	14 (2)
	3.2	13 (2)
1030	> 1	7
1170	9.2	6
1250	4.4	6
1380	7.5	5

Ce (6)

18	7.8	$\bar{5}$

I (34)

4.1	1.13†	10
42.7	1.1†	8
111*s*	6.2	7 (5)
112*l*	1.4	3 (5)

La (7)

t	A	n
18	5.9	$\bar{5}$

Nd (6)

18	7.9	$\bar{5}$

P (18)

15*s*	8.4	10
42*s*	1.6	10
25*l*	2.3	6

Black P‡ (11)

0	1.000	0
50	6.62	$\bar{1}$
100	4.21	$\bar{1}$

Pr (6)

18	8.8	$\bar{5}$

S (18)

20	1.9	17 (15)
30	3.9	16 (15)
55	3.95	15
69	1.78	14
110	4.8	12
115*l*	9.5	11

See also p. 141

Se; *see* p. 141

Si, Crystalline (267)

t	A	n
	α–form	
−189	2.90	$\bar{1}$
− 30	1.13	$\bar{1}$
+ 15	9.0	$\bar{2}$
129	5.0	$\bar{2}$
210	3.9	$\bar{2}$

$\alpha = 3.682$, $\beta = -8.4$, $q = 800$

Si.—(*Continued*)

t	A	n
	β–form	
210	1.62	$\bar{1}$
435	8.5	$\bar{2}$
	γ–form	
440	1.00	$\bar{1}$
835	2.2	$\bar{2}$

$\alpha = 5.04$, $\beta = -3.1$, $q = 3000$

Te; *see* p. 142

Compounds; Standard Arrangement

v. Vol. III, p. viii

Bi_2O_3 (21)

t	A	n
225	2.34	8
424	1.44	5
645	6.01	3

SiO_2; *see* Table 2

TiO_2 (42)

915	11.73	3
1000	7.49	3
1320	4.40	2

SnO; $\rho <$ for SnO_2 (42)

SnO_2 (42)

785	6.56	3
1000	2.56	2
1320	1.01	1

SnAs (32)

− 81	7.97	$\bar{5}$
+ 25	4.97	$\bar{5}$
250	6.36	$\bar{5}$

Sn_2As_3 (32)

− 81	7.21	$\bar{5}$
+ 25	3.67	$\bar{5}$
250	6.32	$\bar{5}$

Sn_2As_2 (32)

− 81	8.58	$\bar{5}$
+ 25	6.43	$\bar{5}$
250	7.91	$\bar{5}$

PbO (21)

384	2.59	7
572	2.67	5
787	1.22	3

PbO_2§ (33)

t	A	n
0	9.08	$\bar{5}$

a = 0.6, if $22° \leq t \leq 84$°C

ZnO (42)

160	9.34	3
605	5.9	1
1000	2.60	0
1320	1.66	0

CdO (42)

785	6.73	3
1000	7.13	2
1200	3.26	1
1330	5.0	0

CuO (21)

12.2	2.12	6
265	3.55	3 (42)
463	1.67	2
750	2.08	0 (42)
1000	3.2	$\bar{1}$ (42)
1038	9.6	$\bar{2}$
1120	1.5	$\bar{1}$ (42)

MnO; $\rho <$ for Mn_3O_4 (42)

Mn_3O_4 (42)

560	2.01	3
695	3.50	2
1000	1.43	1
1280	7.2	$\bar{1}$

Fe_2O_3 (42)

570	6.24	3
700	10.38	2
1000	8.23	1
1015	6.84	1

Fe_3O_4 (42)

t	A	n
125	4.74	3
600	1.32	1
1000	2.17	0
1320	7.7	$\bar{1}$

NiO (42)

590	6.70	3
700	1.02	3
1000	1.44	2
1245	2.4	1

Cr_2O_3 (42)

345	12.65	2
750	7.8	1
1000	4.0	1
1215	2.13	1

WO, Blue; ρ very low (42)

WC (1)

25	1.2	$\bar{5}$

W_2C‖ (1)

25	8.1	$\bar{5}$
1382	1.05	$\bar{4}$
1942	1.25	$\bar{4}$

U_3O_8, ρ very low (42)

CeO_2 (42)

830	2.24	3
1000	2.13	2
1210	1.87	1

MgO (21)

t	A	n
471	2.71	8
933	2.4	5
1280	1.0	5
1341	2.25	6

CaO (21)

763	7.25	8
1011	2.06	7
1466	9.6	2

BaO (21)

307	1	6
355	1.66	4
497	2.17	1

Na_2O_2 (21)

20	2.5	4
109	6.0	3
284	1.0	3

* For B, ρ varies with emf (29).
† $\rho_t = \rho_0 e^{\lambda t}$; for I, $\lambda = -0.126$.
‡ Variation with pressure (11). Unit of P = 1000 kg/cm².

P	ρ/ρ_0 0°	50°	100°
0	1.000	0.662	0.421
1	0.796	0.521	0.323
2	0.643	0.406	0.250
4	0.372	0.239	0.1517
8	0.1079	0.0766	0.0542
12	0.0297	0.0238	0.0209

§ Electrolyzed crystalline plates.
‖ Carbonized W filaments.

TABLE 2.—ELECTRICAL RESISTIVITY (ρ) OF MINERALS AND OTHER SINGLE NON-METALLIC CRYSTALS

$\rho = A \times 10^n$; $\rho_t = \rho_0\{1 + at(10)^{-3}\}$; $\rho_t = \rho_0\{1 + \alpha t(10)^{-3} \pm \beta t^2(10)^{-6}\}e^{-qt/TT_0}$; $T[T_0]$ = absolute temperature corresponding to t[0°C], $T_0 = 273.1$°K; if $t <$ 0°C use the minus sign before the β. $\rho = f(v)$ denotes that ρ varies with the emf. After the name of the mineral the crystal system to which it belongs is indicated. Iso = Isometric, regular, cubic system, $a = b = c$, $a \perp b \perp c \perp a$; Hex = Hexagonal $a_1 = a_2 = a_3 \neq c$, $c \perp$ plane of a_1, a_2, a_3; Orth = Orthorhombic, $a \neq b \neq c \neq a$, $a \perp b \perp c \perp a$; Mon = Monoclinic, $a \perp b \perp c$, a not $\perp$ c; Tri = Triclinic, three axes, no two mutually $\perp$. These a, b, c are the crystallographic axes. In column (1) the direction of the current with reference to the crystallographic axes is indicated. Unit of ρ = 1 ohm cm = 0.3937 ohm in. Centigrade temperatures, °C.

Sb_2S_3, Stibnite (Orth)

	t	A	n	Lit.
‖c	17	36	6	(30)
‖c	37	2.28	6	(30)
	510	2.74	0	(26)
	570	0.25	0	(26)
	$\rho = f(v)$			(38)

C, Diamond (Iso); *see* Table 1

SiO_2, Quartz (Hex)

‖c	20	1.18	14	(14)
‖c	26.5	2.0	22	(37)
‖c	100	8.18	11	(14)
$\perp c$	20	3.27	16	(14)
$\perp c$	26.4	4.3	24	(37)
$\perp c$	100	1.34	15	(14)
‖c	25	5	16	(49)

See also p. 341

SiO_2 (after fusing)

t	A	n	Lit.
25	1	20	(49)
486	5.58	8	(21)
869	2.41	6	(21)
1288	3.83	5	(21)

See also p. 341

PbS, Galena (Iso)

−180	5.9	$\bar{3}$	(25)
0	2.42	$\bar{3}$	
+ 20	2.65	$\bar{3}$	
340	6.06	$\bar{3}$	

a = 5.24, if $-180° \leq t \leq 150°$

$CuSO_4.5H_2O$ (purified) (Tri)

17	6.7	14	(22)

Cu_6As, Algodonite (Orth)

	4.15	$\bar{5}$	(9)
	6.34*	$\bar{5}$	

Cu_9As, Whitneyite (Orth)

t	A	n	Lit.
	3.35	$\bar{5}$	(9)
	4.69*	$\bar{5}$	

Ag_2S; $\rho = f(v)$ (18)

FeS, α Pyrrhotite (Hex)

‖c	− 73	6.45	$\bar{4}$	(26)
‖c	0	5.5	$\bar{4}$	
‖c	+ 18	5.35	$\bar{4}$	
‖c	165	4.30	$\bar{4}$	
‖c	350	3.87	$\bar{4}$	
$\perp c$	− 68	5.0	$\bar{4}$	
$\perp c$	0	4.4	$\bar{4}$	
$\perp c$	+ 19	4.23	$\bar{4}$	
$\perp c$	104	3.55	$\bar{4}$	
$\perp c$	310	2.62	$\bar{4}$	

For ‖c, α = 4.75, β = 2.65, q = 610

FeS, β Pyrrhotite (Hex)

‖c	350	3.80	$\bar{4}$	(26)
‖c	445	3.75	$\bar{4}$	
$\perp c$	417	2.5	$\bar{4}$	
$\perp c$	463	2.5	$\bar{4}$	

FeS_2, Pyrite† (Iso)

− 78	2.51	$\bar{2}$	(23)
0	2.40	$\bar{2}$	(23)
0	2.9	$\bar{3}$	(4)
+ 20	2.40	$\bar{2}$	(23)
121	3.00	$\bar{2}$	(23)
340	3.88	$\bar{2}$	(23)

α = 3.65, β = 3.7, q = 240

FeS_2, Marcasite (Orth)

‖b	0	16.56	0	(23)
‖b	16	10.25	0	
‖b	118	2.75	0	
‖b	243	1.30	0	

α = 2.64, β = 9, q = 1850

Fe_2O_3, Specularite† (Hex)

‖c	0	8.2	$\bar{1}$	(4)
‖c	0	8.76	$\bar{1}$	(3)
‖c	16	7.04	$\bar{1}$	(3)
‖c	123	2.69	$\bar{1}$	(3)
‖c	237	1.56	$\bar{1}$	(3)
$\perp c$	0	4.2	$\bar{1}$	(4)
$\perp c$	0	4.31	$\bar{1}$	(3)
$\perp c$	18.3	3.51	$\bar{1}$	(3)
$\perp c$	100	1.75	$\bar{1}$	(3)
$\perp c$	238	0.96	$\bar{1}$	(3)

For ‖c, α = 3.87, β = 0.26, q = 1400 (3)

For $\perp c$, α = 3.83, β = 0.45, q = 1290 (3)

Fe_3O_4, Magnetite‡ (Iso)

	− 61	5.1	$\bar{2}$	(26)
	+ 21	3.6	$\bar{2}$	
	111	2.88	$\bar{2}$	
	190	2.77	$\bar{2}$	
(u)	19	1.98	0	(50)
(v)	17	7.4	1	
(w)	25	1.37	1	
(x)	7	6.0	$\bar{1}$	
(y)	10	2.2	1	

MoS_2, Molybdenite (Hex)

t	A	n	Lit.
− 65	8.3	0	(25)
+ 19.5	7.9	$\bar{1}$	
102	2.1	$\bar{1}$	
	2.6	0	(13)
	1.6	4	

α = 2.6, β = 9, q = 1400
$\rho = f(v)$ (31, 46)

$FeCb_2O_6$, Columbite (Orth)

‖c	16	1.95	8	(30)
‖c	25	1.39	8	
‖c	32	1.0	8	

$(NH_4)_2Al_2(SO_4)_4.24H_2O$ (Iso) purified

17	4.9	14	(22)
63	3.5	12	

CaF_2, Fluorite (Iso)

20	7.9	17	(14)
110	4.21	13	
155	6.67	11	

$CaCO_3$, Iceland spar (Hex)

‖c	20	1.4§	14	(22)
‖c	20	9.5	15	(14)
‖c	100	6.25	10	(22)
‖c	100	2.37	12	(14)
$\perp c$	20	5.5	14	(14)
$\perp c$	27.8	9.9	22	(36)
$\perp c$	100	4.95	11	(14)

$CaCO_3$, Marble

22	5	9	(15)
22	1	9	

$BaSO_4$, Barite (Orth)

‖b	726	1.5	5	(26)
‖b	963	1.0	4	

Polarization emf = 1 to 1.4 volt

NaCl, Rocksalt (Iso)

20	4.6	16	(40)
100	1.38	13	
400	8.27	7	
750	4.28	3	

NaCl, (Iso)

580	1.95	5	(41)
700	1.42	4	
790	2.0	3	

NaBr, (Iso)

440	1.51	6	(41)
600	3.62	4	
740	4.07	3	

$NaNO_3$‖ (Hex) rhombohedric

240	6.25	6	(41)
250	5.27	6	
300	4.54	5	
310	1.82	5	

KCl, (Iso)

520	4.37	6	(41)
600	5.58	5	
760	8.7	3	

KBr, (Iso)

490	3.55	6	(41)
650	6.45	4	
730	8.33	3	

KCl.KBr, Mixed crystal

t	A	n	Lit.
520	2.50	6	(41)
640	1.20	5	
720	1.17	4	

* After fusing.

† For effect of pressure, *v.* Table 5.

‡ Magnetite: $\Delta = (\rho - \rho_p)/\rho$, where ρ_p = value of ρ for a longitudinal compression of 887 kg/cm².

	Source	a	100Δ
(*u*)	New York	6.8	0.52
(*v*)	New York	6.1	2.64 (slaty)

$KAlSi_3O_8$, Orthoclase (Mon)

	t	A	n	Lit.
$\parallel b$	800	8.5	3	(26)
$\parallel b$	1000	0.80	3	

‡Magnetite.—(*Continued*)

	Source	a	100Δ
(*w*)	Russia	5.5	0.40
(*x*)	Arkansas	4.0	0.45
(*y*)	Tilly Foster, New York	7.9	0.15

§ $\log_{10} \rho = 4780/T - 2.17$.

‖ Perpendicular to rhombohedral face $(10\bar{1}1)$.

TABLE 3.—ELECTRICAL RESISTIVITY (ρ) OF NERNST AND AUER MIXTURES CONTAINING RARE EARTHS (48)

For laboratory construction of Nernst filaments, *v.* (20). Unit of ρ = 1 ohm-cm; t = centigrade temperature, °C; $\rho = A \times 10^n$

Mixture	t	A	n
Nernst (oxides of Zr, Y, Er)	230	2.72	6
	303	1.92	5
	400	1.02	4
	571	3.98	2
	922	1.29	1
	1252	3.49	0
Auer (oxides of Ce, Th)	745	2.19	4
	890	7.85	3
	1068	1.99	3
	1211	6.40	2

TABLE 4.—RESISTIVITY OF MIXED LIQUIDS SUITABLE FOR MAKING HIGH RESISTANCES: MIXTURES OF XYLENE AND ETHYL ALCOHOL (12)

P = % C_2H_5OH by weight; $\rho = A \times 10^n$; $\alpha_{15} = \left(\frac{1}{\rho}\frac{d\rho}{dt}\right)_{15°C}$

Unit of ρ = 1 ohm cm; of P = 1%; Temperature = 25.6°C

P	100	25	20	18	16	14	12	10
A	1.44	2.24	1.00	1.88	3.56	6.94	1.73	5.95
n	5	6	7	7	7	7	8	8

P	9	8	7	6	5	4	0
A	1.18	2.66	6.25	1.69	4.72	1.41	>1
n	9	9	9	10	10	11	15

P = 25, α_{15} = 0.0117; P = 10.2, α_{15} = 0.0168; P = 5.5, α_{15} = 0.0124.

TABLE 5.—EFFECT OF PRESSURE UPON RESISTIVITY OF POOR CONDUCTORS (4)

If $\Delta\rho = \rho_p - \rho_1$, where ρ_p, ρ_1 = volume resistivity when hydrostatic pressure = p, = 1, respectively; then

$$a \times 10^{-6} = \frac{\Delta\rho}{\rho_1(p-1)}\left(1 + \frac{1}{2}\frac{\Delta\rho}{\rho_1}\right).$$

TABLE 5.—(*Continued*)

$\rho_1 = A \times 10^n$; $\parallel c$, $\perp c$ denote that the current is $\parallel$, $\perp$ to the crystallographic *c*-axis. Unit of ρ = 1 ohm cm; of p = 1 atmosphere; temperature = 0°C.

Substance			A	n	p	$-a$
FeS_2	Pyrite		2.9	$\bar{3}$	2550	23.1
Fe_2O_3	Specularite	$\parallel c$	8.2	$\bar{1}$	2510	8.2
		$\perp c$	4.2	$\bar{1}$	2520	6.8
Fe_3O_4	Magnetite	*v.* Note,‡ Table 2				
P	Phosphorus	*v.* Note,‡ Table 1				

TABLE 6.—SURFACE RESISTIVITY: EFFECT OF HUMIDITY OF AIR (39)

The ability to maintain a high resistance when surrounded by moist air increases in the order glass, ebonite, amber, sulfur, paraffin. H = relative humidity; R = resistance of a 2 cm length of a polished *amber* cylinder 0.5 cm in diameter; observations made in order of the entries in table. (v.s.) = very small. Unit of $R = 10^{12}$ ohm; of H = 1%. Room temperature.

H	77.5	80	82	85	86	88	90	93	82	96	82	99	82	100	82
R	409	294	204	98	65	40	20	4	198	1.6	94	0.4	42	(v.s.)	1.4

LITERATURE

(For a key to the periodicals see end of volume)

(1) Andrews, *50*, **27**: 270; 23. (2) Artom, *23*, **37**: 475; 02. (3) Bäckström and Reichenheim, *200*, **4**: 167; 07. (4) Beckman, *Diss.*, Upsala, 1911. (5) Beckmann and Faust, *93*, **84**: 103; 14. (6) Benedicks, *95*, **7**: 225; 15. (7) Benedicks, *200*, **13**: 357; 16. (8) Black, *201*, **22**: 393; 24. (9) Borgström and Dannholm, *60*, **58A**: No. 21; 16.

(10) Bridgman, *1*, **38**: 609; 16. (11) Bridgman, *65*, **56**: 61; 21. (12) Campbell, *3*, **26**: 1044; 13. (13) Coblentz and Kahler, *31A*, **15**: 121; 20. (14) Curie, *6*, **17**: 385; 89. **18**: 203; 89. (15) Curtis, *31A*, **11**: 359; 15. (16) Fleming, *325*, **19**: 655; 09. (17) Fleming and Dyke, *46*, **49**: 323; 12. *121*, **68**: 1017, 1060; 12. **69**: 10; 12. (18) Foussereau, *34*, **97**: 996; 83. *6*, **5**:241, 317; 85. (19) Geiger, *2*, **22**: 461; 23.

(20) Griffith, *3*, **50**: 263; 25. (21) Horton, *3*, **11**: 505; 06. (22) Joffé, *8*, **72**: 461; 23. (23) Koenigsberger, *200*, **4**: 158; 07. (24) Koenigsberger and Gottstein, *63*, **14**: 232; 13. (25) Koenigsberger and Reichenheim, *63*, **7**: 570; 06. *190*, **1906 II**: 20. (26) Koenigsberger and Schilling, *8*, **32**: 179; 10. (27) Lenz, *63*, **25**: 435; 24. (28) Lewis and Wheeler, *7*, **56**: 179; 06. (29) Lyle, *2*, **11**: 253; 18.

(30) Martin, *63*, **12**: 41; 11. (31) Ôkubo, *159*, **12**: 229; 24. (32) Padoa, *36*, **55**: 975; 25. (33) Palmaer, *9*, **29**: 415; 23. (34) Pochettino and Fulcheris, *23*, **58**: 311; 23. (35) Rabinovich, *7*, **119**: 79; 26. (36) Richardson, *5*, **92**: 101; 15. (37) Richardson, *5*, **107**: 101; 25. (38) Ries, *8*, **36**: 1055; 11. (39) Schrödinger, *75*, **119 IIa**: 1215; 10.

(40) Seelen, *96*, **29**: 125; 24. (41) Tammann and Veszi, *93*, **150**: 355; 26. (42) Veil, *Thesis*, Paris, 1920. (43) Walden, *Elektrochemie nicht-wässeriger Lösungen*, p. 587. Leipzig, Barth, 1924. (44) Wartenbérg, *63*, **13**: 1123; 12. (45) Wartenberg, *13*, **440**: 97; 24. (46) Waterman, *3*, **33**: 225; 17. *2*, **21**: 540; 23. (47) Weintraub, *78*, **16**: 165; 08. *172* (8th), **26**: 627; 12. (48) Weissenberger, *8*, **49**: 481; 16. (49) Whitman, *48*, **12**: 31; 26. (50) Wilson and Herroun, *5*, **105**: 334; 24.

ELECTRICAL CONDUCTIVITY OF FLAMES

HAROLD A. WILSON

Nearly all data pertaining to the electrical conductivity of flames are purely relative and depend upon the particular flame used; as the temperature of the flame is, in general, not known, the data are not reproducible. Typical data are given in Tables 1 and 2. For additional data and details, the original sources listed in the bibliography should be consulted. *See also Handbuch der Experimental Physik*, Vol. XIII, Part I, Elektrischen Eigenschaften der Flamme, A. Becker, 1929.

TABLE 1.—ELECTRICAL PROPERTIES OF BUNSEN FLAME
Approximately 2000°K

Property	Value	Lit.
Velocity, negative ions (electrons)	2600 cm sec^{-1} per volt cm^{-1}	(4, 6, 18, 31, 32, 36, 38, 39)
Velocity, positive ions	1 or 2 cm sec^{-1} per volt cm^{-1}	(1, 2, 3, 6, 18, 29, 32, 33)
Resistivity	4×10^5 ohm-cm	(4, 32, 38)

TABLE 2.—ELECTRICAL PROPERTIES OF METALLIC VAPORS IN BUNSEN FLAME
Approximately 2000°K

Property	Li	Na	K	Rb	Cs	Unit	Lit.
Conductivity, equal atomic concentrations.	0.5	1	7	12	21	Na = 1	(6, 18, 32, 34, 38, 39)
Atomic concentration, equal conductivities.	1700	440	9	4	1	Cs = 1	(6, 18, 32, 34)
Atoms ionized, concentration very low		1.6	58	69	91	%	(4, 26, 34)

TABLE 2.—(*Continued*)

Property	Lit.
Ionization of alkali vapors approximately agrees with that calculated by Saha's theory	(4, 26, 38, 39)
Hall effect: $Y/X = 2.45 \times 10^{-5}H$; X = longitudinal electric field, Y = transverse electric field due to Hall effect, H = intensity of magnetic field (in gauss).	(11, 12, 13, 18, 33, 40, 41)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Andrade, *3*, **23**: 865; 12. (2) Andrade, *3*, **24**: 15; 12. (3) Andrade, *96*, **22**: 345; 24. (4) Barnes, *2*, **23**: 178; 24. (5) Bauer, *6*, **29**: 5, 244, 372; 13. (6) Becker, in Graetz, *Handbuch Elekt. Magn.*, III. Leipzig, Barth, 1920. (7) Bernini, *59*, **6**: 212; 13. (8) Bryan, *2*, **18**: 7; 21. (9) Bryan, *2*, **23**: 189; 24.
(10) Campetti, *59*, **16**: 115; 18. (11) Heaps, *2*, **7**: 663; 16. (12) Heaps, *2*, **16**: 238; 20. (13) Heaps, *2*, **24**: 652; 24. (14) Kohn, *3*, **44**: 749; 14. (15) Kurze, *3*, **66**: 133; 21. (16) Lauster, *96*, **3**: 396; 20. (17) Marx, *3*, **50**: 521; 16. (18) Marx, in *Handb. Radiologie*, **IV**: 27. Leipzig. Akad. Verlagsges., Second ed., 1927. (19) Marx, *3*, **65**: 657; 21.
(20) McLennan and Keys, *5*, **92**: 591; 16. (21) Moreau, *6*, **27**: 543; 12. (22) Moreau, *34*, **157**: 922; 13. (23) Moreau, *199*, **9**: 273; 12. (25) Moreau, *34*, **157**: 1070; 13. (26) Noyes and Wilson, *21*, **57**: 20; 23. (27) Ricker, *2*, **8**: 626; 16. (28) Saxer, *2*, **3**: 325; 14. (29) Schönborn, *96*, **4**: 118; 21.
(30) Thieme, *7*, **89**: 693; 15. (31) Wilckens, *Diss.*, Heidelberg, 1914. (32) Wilson, *Electrical properties of flames and of incandescent solids*. London, Univ. Press, 1912. (33) Wilson, *2*, **3**: 375; 14. (34) Wilson, *62*, **216**: 63; 15. (35) Wilson, *78*, **44**: 127; 23. (36) Wilson and Bryan, *2*, **23**: 195; 24. (37) Zachmann, *3*, **74**: 461; 24. (38) Bennett, *3*, **3**: 127; 27. (39) Wilson, *5*, **119**: 1; 28. (40) Watt, *2*, **25**: 69; 25. (41) Boucher, *2*, **26**: 807; 25.

ELECTRICAL RESISTIVITY OF ALLOYS, AMALGAMS, AND COMMERCIAL METALS

C. V. DRYSDALE[1]

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In general, this report does not include the effect of either a magnetic field or of illumination upon the resistivity, nor the resistivity of single crystals; the resistivities of pure metals enter only incidentally as terminal members in series of alloys; and only such commercial metals are considered as are of interest to electricians.

With certain obvious exceptions, all data pertaining to the resistivity and its variation with temperature, heat treatment, composition of the alloy, etc. are given in Table 2.

Alloys that have distinctive names and are of special interest to electricians are listed alphabetically in Table 1 which serves as an index to them; there the approximate ranges in resistivity and temperature coefficient are given.

Caution.—The composition and electrical properties of alloys sold under manufacturers' trade names are to a greater or less extent under the control of the manufacturer. The reader cannot, therefore, assume that such an alloy obtained from a manufacturer will have the properties shown below. The data given in this section have been compiled from various sources and for named alloys may be subject to change. For more explicit information the manufacturer should always be consulted.

[1] Assisted by Messrs. A. C. Jolley and S. J. Willis.

SYMBOLS

A	Annealed.
A_t	Annealed from t, °C.
a, b	Coefficients in $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$.
C	Concentration; % by weight of alloying element in total weight of alloy.
C_i	Concentration of total impurities.
Cst	Cast.
D	$D = 100d\rho/dt$, or $D = 100dR/dt$. When inserted in a series of values of t or of ρ_t, the observations show that it applies throughout the range bounded by the adjacent values of t or of ρ_t.
D_t	Value of D when the temperature exceeds t, °C.
D	Drawn (wire).
Dd	Drawn, hard.
Dr	Temper drawn by reheating to t_{Dr}, °C.
e	Coefficients in $\rho = \rho_0 + e_1C_1 + e_2C_2$.
elec	Electrolytic.
F	Forged.
H_t	Hardened at t, °C (*cf.* Q).
Hm	Hammered.
l	Liquid.
k	Per cent decrease in conductivity per 1% concentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$.
N	Normal, normalized (cooled in still air).
O	Before specific heat treatment.
Q	Quenched.
Q_t	Quenched from t, °C.
R	Relative resistivity; frequently the unit is unknown.
R_c	Rolled cold.
s	Solid.
Sat.	Saturated.
Tp	Tempered.
Tp_t	Tempered at t, °C.
t	Temperature, °C.
t_A	Annealing temperature.
t_{Dr}	Drawing temperature; temperature to which the quenched specimen was reheated.
t_m	Melting temperature.
t_R	Room temperature.
t_s	Solidifying temperature.
t_{Tp}	Tempering temperature.
tr.	Trace; very small amount.
vac	In vacuum.
Wk_c	Worked cold.
α, β, γ	Coefficients in $\rho_t = \rho_{t'}[1 + \alpha_{t'}(t - t')10^{-3} + \beta_{t'}(t - t')^2 \times 10^{-6} + \gamma_{t'}(t - t')^3 10^{-9}]$; and similarly for R_t. Unless another value is indicated, t' is 0. When only α or α and β are given, the others are zero.
δ_f	Per cent decrease in ρ on fusion; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$.
δ_c	Increase in ρ due to adding C% of second metal; *see* k.
Δ_H	Per cent increase in ρ due to cold hardening; $\Delta_H = 100 \times (\rho_H - \rho_A)/\rho_A$.
Δ_t	Mean temperature coefficient between 0 and t, °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$.
$_{t_1}\Delta_{t_2}$	Mean temperature coefficient, based on ρ_0, between t_1 and t_2; $_{t_1}\Delta_{t_2} = 1000(\rho_{t_2} - \rho_{t_1}) \div \rho_0(t_2 - t_1)$.
ρ	Resistivity; specific resistance.
ρ_A	Resistivity of annealed specimen. Similarly for ρ_{Tp}, ρ_{Hm}, etc.
ρ_t	Resistivity at t, °C.

SYMBOLES

A	Recuit.
A_t	Recuit de t, °C.
a, b	Coefficients dans l'expression $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$.
C	Concentration; % en poids d'élement d'alliage en poids total d'alliage.
C_i	Concentration des impuretés totales.
Cst	Coulé.
D	$D = 100d\rho/dt$, ou $D = 100dR/dt$. Quand celui-ci est introduit dans une série de valeurs de t ou de ρ_t, les observations montrent qu'il est applicable dans tout l'intervalle compris entre valeurs successives de t ou de ρ_t.
D_t	Valeur de D quand la température est au-dessus de t, °C.
D	Étiré (Fil).
Dd	Étiré, dur.
Dr	Revenu détruit par rechauffage à t_{Dr}, °C.
e	Coefficients dans l'expression: $\rho = \rho_0 + e_1C_1 + e_2C_2$.
elec	Électrolytique.
F	Forgé.
H_t	Durci à t, °C (*cf.* Q).
Hm	Martelé.
l	Liquide.
k	Diminution de conductibilité en pourcent pour 1% de concentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$.
N	Normal, normalisé (refroidi dans l'air calme).
O	Avant le traitement thermique spécifique.
Q	Trempé.
Q_t	Trempé de t, °C.
R	Résistivité relative; fréquemment l'unité de celle-ci n'est pas connue.
R_c	Laminé, froid.
s	Solide.
Sat.	Saturé.
Tp	Revenu.
Tp_t	Revenu à t, °C.
t	Température, °C.
t_A	Température de recuit.
t_{Dr}	Température d'étirage; la température à laquelle l'échantillon trempé a été rechauffé.
t_m	Température de fusion.
t_R	Température de la chambre.
t_s	Température de solidification.
t_{Tp}	Température de revenu.
tr.	Trace; très petite quantité.
vac	Dans le vide.
Wk_c	Travaillé, froid.
α, β, γ	Coefficients dans l'expression: $\rho_t = \rho_{t'}[1 + \alpha_{t'}(t - t')\times 10^{-3} + \beta_{t'}(t - t')^2 10^{-6} + \gamma_{t'}(t - t')^3 10^{-9}]$; et de même pour R_t. À moins d'une autre indication, t' est 0. Quand on ne donne que α ou α et β, les autres coefficients sont égaux à zéro.
δ_f	Diminution en pourcent de ρ lors de la fusion: $\delta_f = 100(\rho_l - \rho_s)/\rho_l$.
δ_c	Augmentation de ρ due à l'addition de C% d'un deuxième métal; *voir* k.
Δ_H	Augmentation en pourcent due au durcissement à froid: $\Delta_H = 100(\rho_H - \rho_A)/\rho_A$.
Δ_t	Coefficient moyen de température entre 0 et t, °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$.
$_{t_1}\Delta_{t_2}$	Coefficient moyen de température basé sur ρ_0 entre t_1 et t_2; $_{t_1}\Delta_{t_2} = 1000(\rho_{t_2} - \rho_{t_1}) \div \rho_0(t_2 - t_1)$.
ρ	Résistivité; résistance spécifique.
ρ_A	Résistivité de l'échantillon recuit. De même pour ρ_{Tp}, ρ_{Hm}, etc.
ρ_t	Résistivité à t, °C.

ZEICHEN

A Ausgeglüht.
A_t Ausgeglüht von t, °C.
a, b Koeffizient von $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$.
C Konzentration; % in Mass von Legierungs Element in gesammter Mass von Legierung.
C_i Konzentration sämmtlicher Verunreinigungen.
Cst Gegossen.
D $D = 100d\rho/dt$ oder $D = 100dR/dt$. Setzt man eine Reihe von Werten für t oder ρ_t ein, so zeigen die Beobachtungen, dass der Wert (D) in dem durch die Nachbarwerte von t oder ρ_t begrenzten Bereiche Gültigkeit hat.
D_t Werte von D wenn die Temperatur grösser ist als t, °C.
D Gezogen (Draht).
Dd Hart gezogen.
Dr Angelassenes Stück gezogen durch Wiedererwärmung auf t_{Dr}, °C.
e Koeffizient von $\rho = \rho_0 + e_1C_1 + e_2C_2$.
elec Elektrolytisch.
F Geschmiedet.
H_t Gehärtet bei t, °C (*cf.* Q).
Hm Gehämmert.
l Flüssigkeit.
k Abnahme in % der Leitfähigkeit pro 1 % der Konzentration: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$.
N Normal, Normalisiert (in ruhiger Luft gekühlt).
O Vor der spezifischen Wärmebehandlung.
Q Abgeschreckt.
Q_t Abgeschreckt von t, °C.
R Relativer Widerstand dessen Einheit häufig unbekannt ist.
R_c Kalt gewalzt.
s Feste Stoffe.
Sat. Gesättigt.
Tp Angelassen.
Tp_t Angelassen bei t, °C.
t Temperatur, °C.
t_A Temperatur des Ausglühens.
t_{Dr} Temperatur beim Ziehen; Temperatur auf welche die abgeschreckte Probe wiederholt erhitzt wurde.
t_m Schmelztemperatur.
t_R Zimmer Temperatur.
t_s Erstarrungstemperatur.
t_{Tp} Temperatur beim Anlassen.
tr. Spur; sehr kleiner Betrag.
vac In Luftleere.
Wk_c Kalt geschmiedet.
α, β, γ Koeffizient von $\rho_t = \rho_{t'}[1 + \alpha_{t'}(t - t')10^{-3} + \beta_{t'}(t - t')^2 10^{-6} + \gamma_{t'}(t - t')^3 10^{-9}]$; in gleicher Weise für R_t Wenn nicht ein anderer Wert angegeben ist, beträgt $t' = 0$. Sind nur α oder α und β angegeben so sind die anderen Null.
δ_f Abnahme in % von ρ beim Schmelzen; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$.
δ_c Zunahme von ρ beim Zusatz von C% des zweiten Metalles; *siehe* k.
Δ_H Zunahme in % von ρ durch Kalthärtung; $\Delta_H = 100\ (\rho_H - \rho_A)/\rho_A$.
Δ_t Mittlerer Temperaturkoeffizient zwischen 0 und t, °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$.
${}_{t_1}\Delta_{t_2}$ Mittlerer Temperaturkoeffizient, auf Grund von ρ_0 zwischen t_1 und t_2; ${}_{t_1}\Delta_{t_2} = 1000(\rho_{t^2} - \rho_{t_1}) \div \rho_0(t_2 - t_1)$.
ρ Widerstand; spezifischer Widerstand.
ρ_A Widerstand der ausgeglühten Probe. In gleicher Weise für ρ_{Tp}, ρ_{Hm}, u. s. w.
ρ_t Widerstand bei t, °C.

SIMBOLI

A Ricotto.
A_t Ricotto a t, °C.
a, b Coefficienti in $(\rho_t)_{Hg}/(\rho_t)_{Amalgam} = a + bt(10)^{-6}$.
C Concentrazioni; % in peso del'elemento in peso totale delle leghe.
C_i Concentrazioni delle impurezze totali.
Cst Gettato.
D $D = 100d\rho/dt$, o $D = 100dR/dt$. Quando inserito in una serie di valori di t o di ρ_t le osservazioni mostrano che si applica per tutto il campo limitato dai valori adiacenti di t o di ρ_t.
D_t Valore di D quando la temperatura è al di sopra di t, °C.
D Trafilato.
Dd Trafilato, duro.
Dr Rinvenuto per riscaldamento a t_{Dr}, °C.
e Coefficiente in $\rho = \rho_0 + e_1C_1 + e_2C_2$.
elec Elettrolitico.
F Forgiato.
H_t Indurito a t, °C (*cf.* Q).
Hm Martellato.
l Liquido.
k Diminuzione per cento della conduttività per 1 % di concentrazione: $\rho_c - \rho_{c=0} = kC\rho_c/100 \equiv \delta_c$.
N Normale, normalizzato (raffreddato all'aria calma).
O Prima del trattamento termico specifico.
Q Temprato.
Q_t Temprato da t, °C.
R Resistività relativa; spesso l'unità è sconosciuta.
R_c Laminato a freddo.
s Solido.
Sat. Saturato.
Tp Rinvenuto.
Tp_t Rinvenuto a t, °C.
t Temperatura, °C.
t_A Temperatura di ricottura.
t_{Dr} Temperatura di rinvenimento; temperatura alla quale il campione temprato veniva riscaldato.
t_m Temperatura di fusione.
t_R Temperatura ambiente.
t_s Temperatura di solidificazione.
t_{Tp} Temperatura di rinvenimento.
tr. Traccia; piccolissima quantità.
vac Nel vuoto.
Wk_c Lavorato a freddo.
α, β, γ Coefficienti in $\rho_t = \rho_{t'}[1 + \alpha_{t'}(t - t')10^{-3} + \beta_{t'}(t - t')^2 \times 10^{-6} + \gamma_{t'}(t - t')^3 10^{-9}]$; e similmente per R_t. A meno che sia indicato un altro valore t' è 0. Quando sono dati α o α e β, gli altri sono zero.
δ_f Diminuzione per cento in ρ nella fusione; $\delta_f = 100(\rho_l - \rho_s)/\rho_l$.
δ_c Aumento in ρ dovuto all'aggiunta di C % del secondo metallo; *vedi* k.
Δ_H Aumento per cento in ρ dovuto all'indurimento prodotto dalla lavorazione a freddo; $\Delta_H = 100(\rho_H - \rho_A)/\rho_A$.
Δ_t Coefficiente di temperatura media tra 0 e t, °C; $\Delta_t = 1000(\rho_t - \rho_0)/\rho_0 t$.
${}_{t_1}\Delta_{t_2}$ Coefficiente di temperatura media basato su ρ_0, tra t_1 e t_2; ${}_{t_1}\Delta_{t_2} = 1000(\rho_{t_2} - \rho_{t_1}) \div \rho_0(t_2 - t_1)$.
ρ Resistività; resistenza specifica.
ρ_A Resistività del campione ricotto. Similmente per ρ_{Tp}, ρ_{Hm}, ecc.
ρ_t Resistività a t, °C.

TABLE 1. NAMED ALLOYS

The following list contains primarily those alloys that are electrically interesting. More exact and detailed information will be found at the pages indicated.
Unit of ρ = 1 microhm-cm = 10^{-6} ohm-cm; of α = 0.1% per 1 °C

Name	ρ	α	Page
Advance	48–49	0.01–0.02	169, 170
Alumel	33.3	1.2	194
Aluminium bronze	3–13	0.3–3.8	162
Aluminium bronze	15	0.64	167
American nickel	73	1–5	196
Argentan	42		171
Beacon alloy	60–80	0.7	196
Brass	5–7	1.4–2	172
Bronze	13–18	0.5	171, 172
Calido	110	0.12	194
Calorite	110		194
Cast iron	57–114		188
Cementite	45		182
Chromax	(Nichrome IV)		193,
Chromel	70–110	0.11–0.54	193, 194
Cimet	17–44		178
Climax	87	0.67	185
Comet	95.6	0.34	185
Constantan	47–51	−0.04–(+0.01)	169, 170
Copel	49.5	Nil.	169
Dowmetal	13–17		162
Duralumin	3.35		162
Duriron	63	4.9	188
Eureka	(Constantan)		169
Eutectoid	20		178
Excello	92	0.16	193, 194
Excelsior	6–80	0.95–1.4	169
Extra Prima	29.4	0.28	196
Fagersta steel	12.6–21		182
Ferrite	9.5		182
Ferro-nickel	28	2.1	185
Ferrozoid	84		196
Ferry	47		196
German silver	17–41	0.04–0.38	170, 171
Gysinge steel	10–50		182
Hadfield Mn-steel	29–67	1.2–2.0	182, 185
Ia-Ia	47–51	−0.04–(+0.03)	169
Ideal	49	0.005	169
Invar	75	2	185
Karma	103	0.1	193, 194
Kromore	(Nichrome III)		193, 194
Krupp	85	0.7	196
Kruppin	83–85	0.7–1.3	185
Lipowitz alloy	47–53	2.7	165, 197
Lucero	46	0.76	170
Magno	20	0.005	194
Maillechort	(German silver)		171
Mangaloy	107	0.073	196
Manganese nickel	15		194
Manganin	34–100	−0.03–(+0.02)	168
Monel	42.5–45	0.02–2.0	170
New metal	51	−0.038	196
New silver	(German silver)		170, 171
Nichrome	110	0.4–0.03	193
Nichrome II	109–111	0.15	193
Nichrome III	90–97	0.05–0.19	193
Nichrome IV	98–103	0.18	193
Nickel silver, 18%	30–33	0.3	171
Nickeline	27–45	0.02–0.34	171
No. 3 alloy	114		193
No. 4 alloy	103		185
No. 141 alloy	22–30		194
No. 193 alloy*	87–96	0.014–0.8	185, 186
Patent nickel	33–34	0.19–0.21	169, 170
Phosphor bronze†	2–6	3–4	172
Platinite	45	3	185
Platinoid	34–41	0.32–0.25	171
Rayo	96	0.102	171, 194
Resista	76	1.1	196
Resistin	50.2		168
Rheostatine	48	0.25	169
Rheostene	77	1.2	196
Rheotan	48–52	0.24–0.41	171
Rose's alloy	64	1.8	196
Silicon bronze†	2–4	2.3–3.8	172
Silverine	2	2.85	169
Spiegeleisen	105		182, 188
Superior	81–87	0.8–1.1	196
Swedish iron	20	1.2	174
Tarnac	41	0.025	196
Therlo	46.5	0.01	168
Tophet	107		194
Vestalin	83–85	0.7–1.3	185
Welding iron	18	6	175
Wood's metal	51.7	2.9	196

* Driver-Harris Co.
† Telegraph and telephone wires.

TABLE 2.—RESISTIVITY OF ALLOYS, AMALGAMS, AND COMMERCIAL METALS

(For effect of small amounts of impurities in "pure" metals, *v.* p. 135; for general trend of the variations of resistivity with composition or with temperature, *v.* figures, p. 202; for resistivity of non-mercuric alloys near and above the melting point, *v.* Table 3.)

Arrangement of alloys is, in general, alphabetical by "type formula," which consists in each case of the chemical symbols of the essential constituents written in descending order of the amounts of the constituents except that for a steel, C is always written last. In certain cases, alloys of different type formulae are combined in a single group; in such cases, the type formula for the group contains the symbols of all the constituents of the group, and those that are not common to every member of the group are enclosed in ( ). Thus Al-Fe-(Cu, Mn, Si) indicates that Al and Fe are common to every member of the group, but neither Cu, Mn, nor Si is common to all. If the concentrations cover the entire range on both sides of 50%, the entire series is given under the first of the two type formulae; *e.g.*, all of the Ag-Al data are given under Ag-Al, and under Al-Ag there is merely a cross-reference. If on one side of the 50% concentration there are very few data, all of the data are given under the entry appropriate to the more numerous. There are certain obvious irregularities at the beginning of the Fe data.

Alloys with distinctive names are indexed in Table 1.

Room temperature (17 to 23°C) is to be assumed unless another is indicated. All temperatures are expressed in °C; concentrations in weight % unless another is indicated; resistivities in microhm-cm (= 10^{-6} "ohm per cm cube") unless the experimenter used an assumed value for the resistivity of a standard metal, in which case this is indicated by the form "(For Ag, ρ_0 = 1.54)." Units of the other quantities accord with the definitions of the corresponding symbols (*see* p. 157).

TABLE 2.—(*Continued*)

Ag-Al

Al (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	1.47	1.52	4.15	3.97
1.3	11.05	10.87	0.57	0.65
2.7	16.9	16.5	0.45	0.58
6.1	31.1	31.75	0.47	0.27
7.7	36.4	34.7	0.69	0.75
8.6	46.7	33.0	0.44	0.67
10.0	35.3	32.8	0.51	0.71
11.1	33.9	32.4	0.65	0.80
12.9	31.4	30.9	0.67	0.74
14.1	26.0	27.6	1.35	1.07
15.7	26.3	29.3	0.92	0.90
16.7	25.7	29.6	0.86	0.76
20.0	18.5	27.25	1.06	0.66
28.1	13.9	20.8	1.17	0.63
37.5	9.71	17.55	1.56	0.79
50.6	6.85	13.5	1.80	0.68
69.6	5.46	8.0	2.03	1.39
83.1	4.53	5.13	2.10	1.52
100.0	2.49	2.60	4.25	4.10

94% Al (63, 76)

t	ρ_t	t	ρ_t
−197.1	2.484	+0.9	4.654
−106.1	3.477	16.25	4.824
− 81.9	3.723	92.5	5.686
0.0	4.641	$\alpha_{15} = 2.38$	

Ag-Au (19); *cf.* (182, 189)

Au	ρ_0	α	Au	ρ_0	α
3.51	2.29	2.66	76.83	9.925	0.79
14.45	4.295	1.47	85.85	8.0	1.02
32.29	7.645	0.90	94.14	4.925	2.89
52.27	10.09	0.72	98.84	2.76	3.90
66.01	10.21	0.72			

Annealed (182, 188, 189)

Au	ρ_0	α_0	β_0
31.3	6.96	0.91	0.18
67.1	10.2	0.72	0.02
88.0	7.16	1.14	0.13

Drawn (wire)

Au	ρ_0	α_0	β_0
31.3	6.97	0.89	0.25
67.1	10.24	0.67	0.21
88.0	7.24	1.09	0.39

90% Au (63, 76)

t	ρ_t	t	ρ_t
−197.1	4.817	+0.9	6.293
−106.1	5.510	16.4	6.417
− 81.9	5.666	91.65	6.997
0	6.280	$\alpha_{15} = 1.25$	

66.67% Au (230); for Ag, $\rho_0 = 1.54$

	ρ_0	α		ρ_0	α
Hard.....	10.24	0.65	Soft.....	10.21	0.87

Ag-Au-Cu; *v.* Au-Ag-Cu

Ag-Bi (182)

Bi	ρ_t	t	Bi	ρ_t	t
0.0	1.54	0.0	88.5	86.5	20.3
2.2	3.22	22.9	94.0	93.4	21.6
16.0	19.05	20.3	95.8	116.6	19.9
49.0	33.0	22.4	97.9	135.0	21.4
65.8	46.7	21.4	99.0	138.7	21.4
79.4	62.8	20.1	99.7	137.4	21.3

Ag-Cu

Cu (153)	ρ_{25}		$_{25}\Delta_{100}$	
	A	O	A	O
0.0	1.620	1.684	4.17	3.97
0.2	1.700		3.99	
2.4	1.822	1.909	3.81	3.49
4.2		2.053		3.23
6.2	1.914	2.110	3.74	3.03
16.4	1.845	2.181	3.65	3.00
28.1	1.844	2.130	3.76	3.23
41.8	1.913	2.162	3.80	3.20
57.9	1.909	2.284	3.74	2.93
77.95	1.895		3.87	
91.80	1.832	2.271	3.89	3.21
95.02		2.169		3.15
96.65	1.875	2.030	3.85	
98.31		1.902		3.61
99.15		1.856		3.91
100.0	1.706	1.750	4.33	4.11

Dd, for Ag, $\rho_0 = 1.54$ (182, 188, 189)

Cu	ρ_t	t	α	β
0.00	1.54	0		
1.31	1.57†	9.8	3.37†	4.25†
1.31	1.63	9.8		
1.71	1.84	17.0		
2.76	1.97	17.1		
5.26*	2.07	16.8		
7.11	1.91†	9.0	2.75†	3.24†
7.11	1.97	9.0		
11.43	2.285	17.5		
15.6	2.42	17.0		
25.5	2.42	17.2		
35.15	2.37	19.6		
41.4	2.28	19.0		
42.7	2.02†	14.2	2.81†	2.59†
42.7	2.14	14.2		
59.5	2.26	22 2		
63.8	2.27	19.0		
74.7	2.19†	14.6	3.04†	3.16†
74.7	2.31	14.6		
75.5	2.27	18.8		
88.3	2.20	21.1		
94.0	2.04	20.0		
94.4	1.87†	16.0	3.25†	4.65†
94.4	1.97	16.0		
97.6	1.94	19.7		
98.1	1.71†	9.5	3.45†	3.93†
98.1	1.78	9.5		
98.7	1.772	20.7		

* For 5.3 % Cu, $\Delta_H = 8.6$ if $t_A = 700°C$ (112).
† From (188).

Ag-Mg (254)

Mg	ρ_{25}	α_{25}*
0.00	1.637	
0.04	1.78	3.81
0.1	2.14	3.21
0.17	2.23	
0.24	2.52	
0.82	3.41	
1.55	4.65	
2.91	6.28	
6.75	6.85	1.93
7.55	6.86	
8.89	6.83	1.61
9.60	7.05	1.71
10.31	7.25	
11.31	7.28	
13.14	7.67	1.65
17.11	6.77	1.99
17.87	5.88	2.34
18.65	4.87	3.10
19.82	5.73	2.70
20.26	5.82	
21.6	6.27	2.31
23.03	7.82	
23.1	7.74	2.05
28.00	11.74	1.79
32.21	13.53	2.02
34.73	17.99	1.78
35.1	15.01	1.81
38.28	16.93	2.46
39.57	16.53	2.90
39.68	16.23	3.09
43.67	22.05	1.59
44.39	19.7	2.32
62.67	14.31	2.10
72.31	11.25	
79.34	9.91	
83.88	9.42	
89.29	8.54	
89.46	8.19	2.56
91.75	7.17	
93.45	7.27	
96.2	6.87	
98.08	5.96	
100.0	4.61	3.98

* 25 to 100°C.

Ag-Pb (182, 188, 189)

Pb	ρ_t	t
0.00	1.54*	0
0.96	2.294	23.4
14.5	3.225	23.8
32.4	9.85†	13.9
49.0	13.17‡	16.5
65.8	14.41	15.6
78.3	17.15	26.1
8 .4	18.14	26.6
95.1	19.11§	24.3
97.9	19.47	25.3

* Assumed as basis.

† $\rho_0 = 7.04$; $\alpha_0 = 2.0$; $\beta_0 = 1.38$ (189).

‡ $\rho_0 = 11.43$; $\alpha_0 = 1.96$; $\beta_0 = 0.75$ (189).

§ $\rho_0 = 16.66$; $\alpha_0 = 3.62$; $\beta_0 = 5.16$ (189).

Ag-Pd

Pd (81)	ρ_0	α_0*
0	1.57	4.1
10	6.05	0.91
20	10.43	0.47
30	15.4	0.36
40	21.75	0.36
50	32.8	0.26
60	42.0	0.03–0.07
70	38.77	0.25
80	30.68	0.66
90	20.6	1.17
100	10.56	3.28

* 0 to 160°C.

Pd (173, 188, 189, 190)	α_0	β_0
20	0.4336	0.2067
25	0.3576	0.1161
25*	0.3246	0.0488
25†	0.32	−0.05

* From (190).

† From (188, 189); $\rho_0 = 18.08$ if for Ag, $\rho_0 = 1.54$.

20% Pd (62)

t	ρ_t
−182	13.797
−100	14.256
− 80	14.482
+ 0.8	14.965
20	14.984
99.8	15.409

Ag-Pt (277)

Pt	ρ
0.0	2.17
10.39	9.18
20.59	18.14
31.46	29.14
37.89	31.10

33% Pt, 66% Ag (63); *cf.* (62)

t*	ρ_t
−197.1	30.173
−166.1	30.790
− 81.9	30.964
0.0†	31.582†
+ 1.85	31.573
16.1	31.726
93.25	33.296

$\alpha_{15} = 0.243$

* Pt scale of t.

† Same values given (76) for $PtAg_4$ (=31.1 % Pt) (58).

32% Pt, 67% Ag (58)

ρ_0	α
28	0.24

0° (273)

Pt	C_i*	ρ	α
28.95	0.55	29.0	0.261
32.95	0.40	29.9	0.262

* For analysis, *see* (273).

Ag-Pt.—(*Cont'd*)

Pt (273)	α
25	0.377
25	0.407
30	0.313
33⅓	0.301
33⅓	0.265
40	0.259

Dd (188, 189)

Pt	ρ_0	α	β
5.0	4.87	1.24	+0.40
9.8	8.53	0.77	−0.06
33.3	23.0	0.33	−0.10
35*		0.348o	−0.2807

* From (173).

67%Pt, 33%Ag

ρ_0	α_0	Lit.
24.2	0.24–0.33	(144)

Ag-Sb (119)

Sb	ρ_{18}	
27.34	107.5	$SbAg_3$

Ag-Sn (182, 189)

Sn	ρ_t	t
0.00	1.54	0.0
0.65	4.31	20.7
1.41	6.43	20.6
4	16.92*	54.09
51.8	10.73	20.6
68.3	12.23†	19.8
76.4	12.58	23.3
86.6	13.35	20.1
90.7	13.32	20.1
92.8	13.31	20.3
95.1	13.43‡	20.3
96.4	13.43	20.3
99.0	13.54	21.9

* From (244); $\alpha_0 = 0.724$ if $54° < t < 78°$.

† $\rho_0 = 10.8$; $\alpha_0 = 3.77$, $\beta_0 = 5.68$ (189).

‡ $\rho_0 = 12.33$; $\alpha_0 = 3.72$, $\beta_0 = 6.39$ (189).

Ag-Te; *v.* Te-Ag

Ag-Tl (244)

Tl	ρ_t	t	α_0
2.73	4.73	23.58	1.05*
4.76	7.57	49.33	1.25†

* 23 to 38°C. † 49 to 89°C.

Al, Commercial; *v.* Al-Fe-Si

Al-Ag; *v.* Ag-Al

Al-Bi; elect. Bi

Bi (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
6.52	2.92	3.12	4.20	4.08
15.56	3.29	3.51	4.18	3.82
28.7	3.60	3.83	3.91	3.43
60.8	7.81	8.55	3.38	2.38
78.4	19.28	19.46	3.24	1.58
89.4	45.67	45.88	2.85	1.50
97.05	73.0	91.75	3.22	1.17
98.5	106.4	120.5	3.39	1.21
99.4	117.6	142.9	3.98	2.25
100.0	107.5	117.6	4.78	4.31
100.0	107.5*	164.0*	4.78	0.82

* Commercial Bi.

Al-Ca (30)

Ca	ρ	Ca	ρ	Ca	ρ
3.07	15.8	23.9	99.5	37.7	110.0
6.0	20.2	25.0	113.4	50.0	141.0
9.1	27.1	28.5	117.0	60.0	171.0
12.5	38.4	31.3	118.0	75.0	189.0
19.4	49.5	32.8	112.0	78.8	112.0

Al-Cu; *v. also* Table 3

Cu (34, 38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
3.80	3.23	4.26	3.75	2.93
8.66	3.59	4.53	3.43	2.06
18.5	3.94	5.29	3.25	2.10
28.2	4.31	5.40	3.04	1.90

Al-Cu.—(*Continued*)

Cu (34, 38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
39.2	5.08	5.99	2.68	1.96
48.4	5.75	6.33	2.45	2.15
51.3	6.06	6.67	2.31	2.20
54.0	6.58	7.19	2.23	2.25
60.5	7.09	8.07	2.22	2.05
66.9	7.69	8.70	2.11	2.01
70.3	8.27	10.94	2.08	1.09
74.4	10.20	14.67	1.47	0.91
77.1	11.6	15.3	1.18	0.99
78.0	11.3	15.4	1.41	1.02
78.6	28.1	28.6	0.80	0.80
79.8	28.9	28.25	0.65	0.62
82.6	21.2	15.5	0.70	0.58
86.1	15.8	12.0	0.91	1.20
89.0	13.7	7.46	1.40	1.66
90.5	11.8	14.6	1.13	0.71
93.1	10.85	13.3	0.97	0.59
95.3	9.95	10.4	0.81	0.55
98.8	5.85	5.72	0.85	0.86
100.0	1.54	1.56	4.28	4.25

Aluminium bronze (212, 214); *cf.* Cu-Al-Ni

Cu	ρ_0	α_0	β_0	t	ρ_t
6	3.10	3.8	3	−197.1	0.719
90	12.61	0.32	2	−106.1	1.715
92.5	13.62	0.36	1	− 81.9	1.960
94	11.62	0.55	2	0.0	2.904
95	10.21	0.70	2	+ 0.95	2.911
97	8.26	1.02	3	16.35	3.087
				92.4	3.972
				α_{15} = 3.81	

6% Cu (63, 76)

Al-Cu-Fe-Si

15°C; (t_A = 435°C) (1/100%) (205, 295, 297)

Cu	Fe	Si	ρ_A	ρ_O	Δ_{100}*
2	15	16	2.75†		
11	37	31	2.83	2.92	3.18
16	25	38		2.88	3.24
158	25	38	3.30	3.34	2.83
186	31	40	3.18	3.25	3.03
261	40	40	3.26	3.34	2.96
9	116	35	2.96	2.97	3.57

* Unannealed. † t = 20°C (205).

Al-Cu-Mg-Fe-Si, Duralumin wire

t_A = 400°C, 0.41% Fe, 0.22% Si, 2.58% Cu, 1.26% Mg, ρ_A = 3.35 (195)

Al-Cu-Ni-Fe-Si

t = 12 to 14°C, t_A = 450°C, Fe = 0.14 to 0.17%; Si = 0.12 to 0.17% (226)

Cu	Ni	ρ_A	Cu	Ni	ρ_A
0	1.87	2.96	2.00	1.12	3.28
0	4.31	3.19	3.05	1.00	3.42
0.99	0.90	3.22	4.07	1.12	3.32
1.03	3.04	3.34	4.13	2.16	3.55

Al-Fe

Fe (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.44	2.60	4.25	4.10
12.8	6.49	6.76	3.51	2.96
24.3	13.3	14.2	3.19	2.26
33.6	43.3	44.8	2.56	1.53
40.5*	140.8	166.6	1.68	0.23
49.9		833		0.10

* Al_3Fe.

Al-Fe-(Cu, Mn, Si); *v.* Al-Mn-Fe-Si-Cu

Al-Fe-Ni-Si-Cu; *v.* Al-Ni-Fe-Si-(Cu)

Al-Fe-Si (211, 214)

Impure Al; 0°C; (1/100%); tr. of C

Fe	Si	ρ_0	α_0*
7	6	2.72	4.2
12	tr.	2.75	4.0
25	12	2.80	4.6

* β_0 = 4; 0° < t < 370°.

Commercial Al, t_A = 450°C, (1/100%) (110)

Casting

Fe	Si	ρ_A
18	23	2.93
49	47	3.08

Al-Fe-Si.—(*Cont'd*)

Fe	Si	ρ_A
83	16	3.02
130	32	3.23

Wire and laminae

Fe	Si	ρ_A	Δ*
24	25	2.84	0.04
42	51	2.91	0.11
53	68	2.93	0.20
91	89	2.99	0.28

* $\Delta = \rho_O - \rho_A$.

(1/100%) (297)

Fe	Si	ρ_{15}	Δ_{100}
31	14	2.76	3.93

Al-Fe-Si-Cu; *v.* Al-Cu-Fe-Si

Al-Mg

Mg (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
3.76	6.02	6.45	2.10	1.92
6.92	6.99	7.09	1.80	1.80
14.46	10.41	10.42	1.17	1.34
18.06	12.20	12.36	0.94	1.09
21.79	14.71	14.97	0.65	0.91
29.73	26.60	28.40	0.69	0.49
31.23	27.79	31.15	0.45	0.50
35.86	40.66	37.18	0.33	0.34
40.0	49.26	45.46	0.34	0.25
47.75	38.03	37.31	0.47	0.28
52.28	45.06	43.48	0.29	0.26
53.89	38.48	36.36	0.41	0.34
54.95	32.57	31.46	1.44	0.80
57.69	22.07	23.09	4.10	3.75
60.29	30.77	29.86	0.90	1.03
64.74	24.52	27.40	1.02	0.75
73.02	19.92	22.84	1.03	0.84
85.26	16.47	17.30	1.32	1.10
92.85	14.22	14.01	1.45	1.28
100.0	40.64	42.54	4.30	4.15

Mg (64)	ρ	Mg (64)	ρ
85 C*	17.19	94	10.42
88 B*	16.34	96	9.40
90	15.36	98	7.48
92 A*	13.35	100	4.54

* Dowmetal A, B, C.

Al-Mg.—(*Continued*)

Cast rod A_{308} for 15 hr, in vacuum (192)

Mg	α_0	Mg	α_0
31.00	0.1411	43.30	0.0846
34.13	0.1353	44.24	0.3690
34.48	0.1648	44.48	0.4243
35.92	0.2984	47.12	0.5755
39.54	0.2800	50.25	0.4202

Mg (205)	ρ_{20}	Mg (205)	ρ_{20}
10	8.28	90	19.18
12.5	7.61	100	47.5

Al-Mg-Ni (205), with 8% Mg and 2% Ni, ρ_{20} = 7.72

Al-Mn

Mn (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
6.3	14.27	14.6	0.26	0.24
12.6	20.1	20.7	0.34	0.41
21.4	35.7	34.6	0.42	0.70
32.8	84.0	96.6	0.66	0.82
40.4	500	294	1.10	1.22
46.9	2000	714	−0.63	0.42

Al-Mn-Fe-Si-Cu

15°C; (1/100%) (295, 297)

Mn	Fe	Si	Cu	ρ_0	Δ_{100}
5	54	32	2	3.09	3.11
35	35	31	3	3.30	2.91
178	56	44	9	3.49*	2.45

* ρ_A = 3.35.

Al-Ni

Ni (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0	2.49	2.60	4.25	4.10
11.4	4.14	4.0	2.54	2.63
22.4	7.81	7.04	1.56	2.20
30.2	9.9	9.18	1.55	1.74
42.4	28.8	15.15	2.53	1.45
44.6	34.8	23.5	1.12	0.98
83.5	62.9	80.6	1.06	0.62
86.5	59.5	64.5	0.88	0.49
88.5	75.8	72.5	0.67	0.29
92.8	61.4	67.1	0.53	0.19
96.6	24.9	31.25	1.05	0.85
98.4	17.7	17.8	2.07	1.53
100.0	11.96	13.14	5.22	4.98

Al-Ni-Cu-Fe-Si; *v.* **Al-Ni-Fe-Si-(Cu)**

Al-Ni-Fe-Si-(Cu); *v. also* **Al-Cu-Ni-Fe-Si**

15°C; (1/100%) (295, 297)

Ni	Fe	Si	Cu	ρ_0	Δ_{100}
75	25	37	5	3.05	3.20
119	29	35	9	3.24	3.20
225	110	37	6	3.18*	3.29
129	43	37	108	3.41†	1.78
139	257	39	10	3.24‡	3.20

* ρ_A = 3.14. † ρ_A = 3.28. ‡ ρ_A = 3.20.

Al-Ni-Zn-Fe-Si-Cu

15°C; (1/100%) (250, 295)

Ni	Zn	Fe	Si	Cu	ρ_A*	Δ_{100}†
83	90	53	35	10	3.03	3.20
109	73	59	31	19	3.33	3.18
113	194	40	43	21	3.24	3.19
201	177	29	35	11	3.26	2.38
231	38	56	39	24	3.48†	3.00

* $\rho_O - \rho_A$ = 0 to 0.15. † Not annealed.

Al-Si-Fe-Cu; *v.* **Al-Cu-Fe-Si**

Al-Sn*

Sn (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0.0	2.49	2.60	4.25	4.10
12.5	3.66	3.65	2.87	2.79
23.25	4.05	3.85	2.69	2.56
40.1	5.44	4.63	2.55	2.75
52.7	6.99	4.95	2.46	2.99
64.5	8.85	5.78	2.78	2.76
72.9	8.27	6.67	2.75	3.18
74.0	8.85	6.58	2.84	3.03
79.8	9.43	7.46	2.90	2.93
81.5	9.61	7.64	2.78	2.80
86.2	10.19	8.27	3.08	3.24
91.6	10.62	9.17	2.97	3.13
96.25	10.75	10.20	2.93	3.08
98.2	12.12	11.65	3.15	3.50
100.0	11.43	13.00	3.17	3.40

* Impurities in Sn < 0.2 %.

Al-Zn

Zn* (38)	ρ_0		Δ_{100}	
	A	Tp	A	Tp
0.0	2.49	2.60	4.25	4.10
11.3	3.90	3.88	2.23	1.66
21.7	4.97	5.38	1.94	1.20
38.7	5.71	6.49	1.72	1.10
51.9	5.81	6.62	1.63	1.21
63.1	5.95	6.80	1.48	1.12
72.2	5.95	6.90	1.68	1.19
79.9	5.92	6.94	1.59	1.13
85.3	5.95	7.04	1.73	1.29
90.55	6.06	6.90	1.65	1.37
95.5	6.02	6.94	1.86	1.22
98.1	5.95	7.00	2.45	1.56
100.0	5.41	8.93	4.38	2.05

* Al contains 0.1 Fe + 0.2 Si.

Zn (307)	ρ_{t_R}	ρ_{350}	Zn (307)	ρ_{t_R}	ρ_{350}
0.00	2.77		41.08	5.06	10.51
4.89	3.34		48.95	5.14	11.06
8.02	3.67		57.17	5.56	13.52
10.00	4.01		63.77	5.47	13.52
11.98	4.43		70.30	5.56	14.01
15.08	4.63		75.30	5.38	14.01
17.80	4.88		77.95	5.53	14.01
19.44	5.05	9.89	80.00	5.5	13.52
25.00	5.04	9.49	82.30	5.65	14.01
30.82	4.88	9.52	86.10	5.7	14.01
35.20	5.09	10.31	96.05	5.88	15.58

Al-Zn-Cu-Si-Fe; *v.* **Al-Zn-Si-Fe-Cu**

Al-Zn-Ni-Fe-Si-Cu; *v.* **Al-Ni-Zn-Fe-Si-Cu**

Al-Zn-Si-Fe-Cu

15°C; (1/100%) (295, 297)

Zn	Si	Fe	Cu	ρ_0	Δ_{100}
62	38	22	17	2.86	3.57
120	43	28	30	2.94	3.20
204	43	39	9	3.07	3.25
59	37	28	59	3.06	3.06
120	39	31	63	3.12	3.16

Au-Ag; *v.* Ag-Au

Au-Ag-Cu, 20°C (75)

Ag	Cu	ρ_A	Δ_H	α*
4.72	95.28	2.375†		3.12†
6.27	59.25	8.80	3.4	0.763
9.64	5.83	10.84	1.5	0.764
15.64	1.89	9.81	1.2	0.851
3.96	21.60	13.96	0.2	0.516
11.52	16.29	13.65	0.7	0.550
25.34	6.58	12.50	1.4	0.644
32.29	2.11	11.40	2.6	0.693
4.53	29.25	13.60	2.2	0.553
23.34	18.15	12.61	4.8	0.620
36.52	2.46	11.21	0.1	0.653
0.00	49.16	11.37	3.5	0.632
5.43	44.85	11.40	2.8	0.624
15.61	36.8	11.06	5.8	0.631
29.3	26.0	10.46	5.4	0.678
52.3	7.74	9.61	4.5	0.749
58.95	2.48	9.02	3.2	0.779

* Annealed; Wk_e decreases α by 1 % to 6 %. † Cold worked.

Ag (196)	Cu	α_0	β_0
14.3	78.3	1.833	+0.5746
15.2	26.5	0.574_2	−0.5946
18.06	15.44	0.5295	+0.1869

18 Karat Gold (201); Au, 75; Ag, 10–20; Cu, 5–10; $\rho_0 = 8.53$; $\Delta_{100} = 1.08$

Au-Bi; *v.* Bi-Au

Au-Cd (240)

Cd	ρ_{25}		α_{25}*	
	O	Tp	O	Tp
0	2.34	2.296	4.27	4.45
5.05	4.12	4.04	2.41	2.62
14.44	6.675	6.81	2.58	2.44
30.36	13.14	12.36	1.50	1.35
35.44	16.6	15.4	1.19	1.31
40.77	11.31	10.08	1.72	2.16
43.23	10.55	10.03	1.88	2.34
44.05	9.745	10.23	1.92	2.34
46.34	8.365	9.2	2.43	2.67
48.4	7.725	7.71	6.07	6.24
49.76	7.5	7.39	6.55	6.36
50.27	7.32	7.47	5.44	5.67
51.36	8.825	8.72	2.35	3.06
55.89	16.5	14.31	1.74	1.89
60.32	17.6	17.7	1.93	1.93
70.21	14.6	14.73	2.18	2.46
72.93	14.09	14.51	2.05	2.73
74.07	14.0	13.9	3.15	3.50
74.89	13.3	13.27	4.05	4.17
75.87	13.495	15.03	2.56	2.71
78.56	12.5	33.4	2.01	1.64

Au-Cd.—(*Continued*)

Cd	ρ_{25}		α_{25}*	
	O	Tp	O	Tp
81.89	12.01	28.15	2.77	2.35
84.93	11.42	26.45	2.55	2.35
88.01	10.27	18.65	2.94	2.97
89.87	9.375	16.34	3.02	2.60
91.03	9.645	15.17	3.38	2.50
92.17	9.55	14.3	3.13	2.20
92.95	9.57	12.92	2.76	2.84
94.05	9.29	10.9	3.17	3.11
94.95	9.5	9.49	3.31	3.31
98.1	9.36	9.295	3.38	3.39
99.05	9.16	8.95	3.74	3.64
100	7.4	7.26	4.42	4.32

* 25 to 100°C.

Cd	ρ_{150}	α_{100}*	Cd	ρ_{150}	α_{100}*
0	3.56	5.77	51.36	11.63	3.98
5.05	5.12	2.47	55.89	16.54	
30.36	15.22	1.02	60.32	20.67	
40.77	14.23	3.07	100.0	11.55	
48.4	12.14	3.45			

* 100 to 600°C.

Au-Cu

Cu (154)	ρ_{25}		α_0*	
	A	Tp	Tp	A
0	1.7	1.700	4.94	4.94
5	4.797	4.931	1.43	1.44
10	4.246	7.404	0.94	0.93
15	9.117	9.117	0.80	0.77
20	10.803	11.69	0.61	0.78
22.5		12.632	0.55	
25	5.729	12.396	0.59	0.97
27		13.686	0.52	
31.09	9.988	13.592	0.57	1.08
35	4.814	15.803	0.45	0.55
40	11.427	16.026	0.48	0.83
45	9.782	16.551	0.51	1.10
47		16.107	0.43	
49.16		16.292	0.49	
50	5.636	15.142	0.53	1.98
55	10.611	17.045	0.42	0.98
60	11.342	15.870	0.49	0.95
65	14.968	15.727	0.53	0.50
70	15.04	14.171	0.73	0.60
74.37		12.728	0.78	
75	13.233	12.792	0.76	0.66
85	11.095	11.136	0.89	0.76
90	7.738	7.916	0.96	1.14
95	6.858			1.36
100	3.144	3.144	2.93	2.93

* If $25° \lesssim t \gtrsim 100°$.

Cu	ρ_{25}	Cu	ρ_{25}
0	1.700 to 2.062	65	14.814 to 15.445
15	10.804 to 11.388	75	5.533 to 9.005
30	14.727 to 15.040		

For Ag, $\rho_0 = 1.54$ (182, 188, 189); *cf.* (186)

Cu	ρ_t	t	Cu	ρ_t	t
1.1	3.30	19.1	14.5	12.16	19.6
2.0	4.67	19.4	28.9	13.45	17.8
4.1	6.86	17.9	43.0	12.32	20.1
8.2	10.03	20.3	50.7	11.0	17.1

Au-Cu.—(*Continued*)

Cu	ρ_t	t	Cu	ρ_t	t
65.8	7.76	16.9	92.68	2.90	18.0
78.2	5.36	19.5	96.52	2.36	18.1
82.3	4.64	17.0			

Cu (189)	ρ_0	α_0	β_0	Cu (189)	ρ_0	α_0	β_0
0.7	2.74	2.65	2.38	66.2	7.51	0.86	0.18
9.5	9.61	0.75	0.48	98.48	1.83	3.32	3.72

Au-Cu-Ag; *v.* **Au-Ag-Cu**

Au-Fe; *v. also* **Fe-Au**

Wire, Dd (188, 189)

Fe	ρ_0	α_0	β_0	Fe	ρ_0	α_0	β_0
4.74	64.9	0.49	+0.13	9.825	74.7	2.98	−3.35
5.0		0.3720*	−0.3822*	13.55	56.1	3.5	+5.22

* From (173).

Au-Pd (80)

Pd	ρ_0	α_0*	Pd	ρ_0	α_0*
0	2.104	3.26	60	25.26	0.79
10	7.37	0.97	70	20.58	1.31
20	12.60	0.64	80	18.02	1.74
30	18.09	0.55	90	14.26	2.24
40	24.70	0.34	100	10.56	3.28
50	26.32	0.65			

* 0 to 160°C.

Au-Pt (81)

Pt	ρ_0	α_0*	Pt	ρ_0	α_0*
0	2.1	3.26	30	19.3	0.59
10	10.23	0.98	40	32.7	0.37
20	17.95	0.54			

* 0 to 160°C.

Au-Sn (182, 189)

For Ag, $\rho_0 = 1.54$

Sn	ρ_t	t
0.41	7.86	18.8
0.81	11.73	21.4
12.82	29.75	15.0
22.75	17.35	15.9
37.05	10.79	18.1
41.9	17.4	21.0
54.05	30.1	22.3
59.5	36.0*	21.3
63.9	30.9	21.7
70.2	25.1	19.2
78.0	19.85†	19.8
85.2	16.8	24.2
88.6	15.45	23.8
96.75	13.86	23.6

* $\rho_0 = 30.45$, $\alpha_0 = 2.92$, $\beta_0 = 2.23$ (189).

† $\rho_0 = 18.63$, $\alpha_0 = 3.09$, $\beta_0 = 2.88$ (189).

Sn	ρ	(96)
37.6	11.1	AuSn
54.6	33.3	$AuSn_2$
64.4	25	$AuSn_4$

Bi-Ag, Bi-Al; *v.* **Ag-Bi, Al-Bi**

Bi-Au (182, 188)

For Ag, $\rho_0 = 1.54$

Au	ρ_t	t
1.1	152.5	24.0
2.3	154.3	21.6
4.5	141.3	19.9
10.6	123.2	21.9
19.23	108.4	22.6
32.2	84.6	13.7
48.65	52.2	14.3

Bi-Cd-Pb-Sn; *v.* Table 3

Bi-Hg (284); (*cf.* **Hg-Bi**)

Hg	R	t
0.00	1.355	265.0
12.40	1.383	265.7
19.22	1.407	265.2
42.73	1.367	264.0
42.66	1.363	263.5
53.79	1.325	265.8
58.72	1.316	264.0
62.66	1.283	264.6
67.70	1.240	264.0
77.05	1.185	265.2
83.38	1.151	263.6
85.32	1.157	265.0
90.02	1.133	263.9
93.07	1.147	264.9
94.31	1.149	262.8
96.6	1.192	264.7
100.0	1.309	266.0

Bi-Mg (265)

Mg	ρ_{25}	Δ_{100}
1.6	141.6	4.19
2.5	142.6	4.17
4.45	149.3	4.23
6.7	154	4.39
12.5	131.2	3.85
16.5	49.0	3.65
22.1	31.1	3.74
35.4	12.5	4.10

Bi-Pb; *v. also* **Pb-Bi** in Table 3

(182, 188, 189)

For Ag, $\rho_0 = 1.54$

Pb	ρ_t	t
0.3	170.4	25.8
0.4	252.5	23.8
0.50	359.7	24.8
0.55	496.8	25.6
0.7	529.1	25.0
1.0	570.4	21.3
1.6	590.0	22.9
2.0	599.1	24.1
2.4	568.2	24.0
3.4	532.9	23.9
4.0	508.2	23.5
4.7	492.1	21.3
5.8	431.4	22.6
7.6	380.3	21.5
11.1	295.6	20.0
19.9	179.2	19.9
33.3	109.2	19.2
49.9	73.7	22.2
66.9	53.6	22.5
75.0	44.4	21.3
79.95	38.3	21.7
83.3	35.4*	20.9
92.28	27.74	24.4
97.96	21.9†	24.0

* $\alpha_0 = 2.307$, $\beta_0 = 2.0$.

† $\alpha_0 = 3.458$, $\beta_0 = 5.06$.

0°C; $t_A = 123$ (121)

Pb	ρ_O	ρ_A
0.00	131.2	134.5
2	284.8	295.8
4	290.2	271.6
6	275.9	273.1

Bi-Pb.—(*Cont'd*)

Pb	ρ_O	ρ_A
8	266.9	268.4
10	255.4	265.3
20	188.5	179.7
30	137.4	129.7
50	86.06	77.30
60	70.53	65.17
70	53.06	55.96
80	41.41	43.82
82	39.34	40.07
84	40.41	41.73
84.5	39.26	39.59
86	35.34	36.97
87.5	34.09	33.53
88	31.98	32.95
90	29.08	32.21
100.00	20.91	21.39

Pb (242)	ρ	Pb (242)	ρ
0	120.5	1.81	213.7
0.50	130.6	3.11	225.3
0.81	129.7	4.08	194.6
1.77	163.5		

Bi-Pb-Sn; *v.* Table 3

Bi-Pb-Sn-Cd

Lipowitz alloy (169); *v. also* Table 3; *ca.* Bi, 50; Pb, 25; Sn, 14; Cd, 11; H-scale of t.

t	ρ	t	ρ
+ 19.6	47.5	−122.9	28.9
−176.6	21.3	− 92.1	33.2
−178.1	21.1	− 89.1	33.7
−178.5	21.0	− 87.0	34.0
−178.5	20.9	− 85.1	34.3
−175.7	21.0	− 37.4	40.4
−173.4	21.5	− 35.7	40.9
−170.5	21.8	− 35.0	41.0
−141.5	26.1	− 34.6	41.0
−134.6	27.4	+ 12.1	46.7
−129.3	27.9	+ 12.1	46.8
−125.4	28.3		

Bi-Sb (180)

For Ag, $\rho_0 = 1.54$; 3.03% Sb, $\rho_{24} = 174.2$

Bi-Sn (182)

For Ag, $\rho_0 = 1.54$

Sn	ρ_t	t	Sn	ρ_t	t
0.1	142.6	25.2	12.1	148.1	29.9
0.3	386.4	27.1	21.8	68.8	28.5
0.5	583.1	26.3	35.7	38.9	25.7
0.6	628.4	26.8	52.3	26.4	23.8
0.95	604.0	24.1	62.55	21.9	27.9
2.7	432.8	24.7	69.0	19.7	24.9
4.4	300.0	29.7	92.37	14.8	24.2
6.5	243.6	29.6			

Bi-Sn.—(*Continued*)

Sn (285) = 19.67		31.08		39.65	
t	R_t	t	R_t	t	R_t
0	132.8	0	85.0	0	68.7
α_0 = 2.73		α_0 = 3.07		α_0 = 2.59	
D = 36.2		D = 26.1		D = 17.8	
133.0	181.0	132.1	119.5	69.1	81.0
137.3	184.2	139.9	120.9	97.0	88.0
141.6	180.9	143.1	119.4	107.5	90.6
146.3	177.5	149.4	115.2	120.5	92.7
156.0	170.9	156.2	109.7	128.1	93.6
166.3	159.8	161.4	102.1	136.2	94.3
173.2	149.9	165.3	98.5	138.6	94.5
187.4	136.0	185.2	98.9	142.1	93.1
196.4	123.1	204.4	99.2	143.6	91.6
202.1	108.5	D = 3.9		147.3	90.8
214.7	111.1	253.8	101.1	155.5	88.3
D = 3.3		30.6	92.0*	D = 4.3	
260.0	112.6	65.9	99.6	252.8	92.5
34.6	1.443*				
60.0	1.519*				
90.4	1.646				

Sn (285) = 45.5		50.05		61.09	
t	R_t	t	R_t	t	R_t
0	54.4	0	47.7	0	30.4
α_0 = 3.07		α_0 = 3.3		α_0 = 4.64	
D = 16.7		D = 15.8		D = 14.0	
137.9	77.4	129.5	68.1	137.7	49.7
139.8	77.9	135.6	70.8	141.6	50.9
145.3	82.0	141.6	74.4	147.1	53.0
149.4	82.4	148.6	78.7	156.2	57.1
D = 4.5		153.2	79.3	164.3	63.2
251.8	87.0	D = 4.5		172.4	70.5
45.6	61.3*	244.6	83.4	178.2	71.3
73.9	65.4*	58.7	56.3*	D = 3.51	
81.6	66.9*	81.9	59.9*	252.3	73.9
93.7	69.0*			35.9	34.6*
100.9	70.8*			50.2	36.0*
				59.4	37.0*
				74.4	39.1*
				91.0	42.2*

Sn (285) = 75.30		87.46		90.53	
t	R_t	t	R_t	t	R_t
0	26.0	0	18.3	0	16.2
α_0 = 3.22		α_0 = 3.93		α_0 = 3.70	
D = 8.39		D = 7.19		D = 5.98	
133.6	37.2	176.7	31.0	158.7	25.7
135.4	37.2	184.7	32.6	167.0	25.8
137.9	36.5	199.0	38.3	186.2	28.4
141.8	37.0	206.9	47.8	198.2	31.0
144.6	37.4	210.0	54.6	211.5	40.0
151.2	38.4	212.1	57.2	217.4	52.9
157.7	39.6	217.1	57.2	224.7	55.3
179.2	46.9	D = 3.9		239.3	55.4
194.2	60.4	253.0	58.6	251.4	56.0
194.7	62.6	230.7	57.4*		
200.3	63.8				
D = 2.57					
254.8	65.2				
59.5	30.7*				
75.1	31.9*				

* Falls below the line defined by D and its preceding R_t.

Bi-Sn.—(*Continued*)

Sn (242)	0	0.34	0.71	2.15	7.43
ρ	120.5	168.1	197.7	223.3	204.9

Duplicate specimens differ by 2% to 12%; following data are averages for two specimens of each composition (55):

Sn	0	1	2	3.71	6.36
ρ_{20}	111.4	320.8	320.0	307.5	227.7
ρ_{35}	117.3	326.7	327.6	316.6	235.2
ρ_{50}	123.6	332.2	335.3	323.6	242.0
ρ_{65}	130.0	336.2	340.0	330.0	250.0
ρ_{80}	136.8	337.8	344.8	336.0	258.0
ρ_{100}	144.8	340.5	349.1	340.2	267.2

Sn 7.69%, ρ_{22} = 296.6; for Ag, ρ_0 = 1.54 (180)

Bi-Te (119); Te, 47.8%, ρ_{18} = 2000; Bi_2Te_3

Bi-Tl (104)

Tl	ρ	α_0	β_0
0	110	3.32	5.45
1	128	2.62	5.075
10	110	1.68	9.54
20	90	1.89	7.80
30	69	2.41	4.71
37	45	2.90	2.22
40	84.6	1.27	0.591
53	96.8	0.740	0.511
60	105.1	0.418	0.951
80	68.8	0.7125	1.450
85	53.2	0.936	8.32
88.75	42.5	1.177	5.89
90	37.5	1.387	8.01
93	29.5	2.03	18.86
95	24.3	2.76	16.47
97.5	21.4*	3.15	2.10
	21.5†	2.81	5.35
98.5	19.2*	3.28	1.562
	10.4†	3.25	2.58
99.25	17.4	3.79	1.72
100	14.0	4.28	2.14

* αTl. † βTl.

Ca-Al; *v.* Al-Ca

Cd-Au; *v.* Au-Cd

$CdCl_2$-Cd; *v.* Table 3

Cd-Cu (24)

Cu	ρ_{600}	ρ_{700}	Cu	ρ_{600}	ρ_{700}
0.0	34.82	35.78	31.5	44.45	42.43
19.0	42.42	41.57	37.0	42.97	41.77
23.8	43.97	42.31	42.0	41.65	40.71
27.4	43.89	42.07			

Cd-Mg (279)

Mg	ρ_{25}	ρ_{50}	ρ_{75}	ρ_{100}
0.0	7.46	8.077	8.78	9.61
1.1	9.43	10.215	11.15	12.05
2.4	11.45	12.18	13.02	13.90
3.7	14.08	14.83	15.625	16.34
4.15	14.94	15.798	16.567	17.64
5.2	12.00	14.493	17.36	18.73
6.75	16.64	17.482	18.18	18.87
8.5	27.32	29.59	30.52	36.36
9.4	29.41			37.03
10.35	28.33	30.303	33.00	36.36
11.5	20.49			25.0

Cd-Mg.—(*Continued*)

Mg	ρ_{25}	ρ_{50}	ρ_{75}	ρ_{100}
12.6	18.08	18.832	19.88	20.84
15.0	11.97	12.658	13.47	14.24
16.35	9.48	10.183	10.917	11.89
17.8	7.692	8.446	9.225	10.13
19.25	9.22	9.891	10.73	11.56
20.9	10.87	11.494	12.20	13.00
24.5	13.56	14.347	15.083	15.97
28.6	13.87	15.00	16.34	17.67
33.5	12.00	13.28	14.184	15.34
36.3	10.101	10.858	11.82	13.02
39.4	8.85	9.871	11.364	13.16
42.6	8.62	9.578	10.964	12.82
46.4	14.70	15.00	15.29	15.63
55.1	13.44	13.774	14.184	14.49
66.0	10.101	10.493	10.99	10.33
80.4	7.194	7.507	7.855	8.21
100.0	4.608	4.985	5.414	5.959

Mg	ρ_{150}	ρ_{200}	ρ_{255}	ρ_{300}
0.0	11.9	14.2	16.2	17.0
3.7	17.9	19.9	21.8	23.5
5.2	21.7	23.3	25.0	27.0
8.5*	44.25	45.45	46.1	46.95
12.6	25.0	31.25	35.0	35.7
15.0	16.4	18.7	25.6	26.8
17.8†	11.8	14.0	23.3	24.0
20.9‡	14.9	17.0	25	25.8
24.5	18.1	21.4	27.1	27.7
28.6	20.8	25.0	25.6	26.3
36.3	16.67	20.84	21.45	22.26
42.6	17.24	18.8	19.3	19.95
46.4	16.39	17.51	18.18	18.9
55.1	15.23	15.92	16.42	16.92
100.0	7.64	9.8	11.86	13.27

* $\rho_{140} = 42.55$; $\rho_{175} = 44.8$.

† $\rho_{165} = 12.4$; $\rho_{185} = 13.3$; $\rho_{210} = 14.7$; $\rho_{235} = 15.65$; $\rho_{245} = 17.2$; $\rho_{250} = 18.2$; $\rho_{275} = 23.75$.

‡ $\rho_{163} = 15.4$; $\rho_{190} = 16.4$; $\rho_{233} = 20.0$; $\rho_{243} = 24.9$.

Cd-Pb; *v. also* Table 3

Pb [19]	ρ_0	Δ_{100}	Pb*	ρ_t	t
13.03	7.46	4.17	23.6	8.12	21.4
30.76	8.51	4.19	31.6	8.70	20.7
40.92	9.44	4.01	48.1	10.52	21.2
57.71	10.9	4.13	64.9	12.22	21.8
69.35	13.2	3.95	78.8	15.10	18.5
80.84	15.32	4.26	88.1	17.13	23.0
91.57	17.63	4.12	92.6	18.37†	21.9

* For Ag, $\rho_0 = 1.54$ [182, 188, 189].

† $\rho_0 = 16.58$; $\alpha_0 = 3.50$; $\beta_0 = 5.0$ [189].

Cd-Sb [72]

Sb	ρ_0	ρ_{-79}	ρ_{-190}
33.3	372	292	156.8
50.0	1 699	1 257	730
51.7*	50 200	31 800	15 970
66.7	4 050	3 675	4 940

* CdSb.

Cd-Sn [182, 188, 189] For Ag, $\rho_0 = 1.54$

Sn	ρ_t	t
14.7	7.54	20.5
20.6	7.85*	20.3
34.2	8.39	19.6
50.9	9.54	20.9
66.6	10.66	20.2
80.6	11.63†	22.3
86.1	12.10	22.1

Cd-Zn [182, 188, 189] For Ag, $\rho_0 = 1.54$

Zn	ρ_t	t
8.9	6.85	19.4
12.7	6.74	20.3
22.3	6.57‡	21.3
36.8	6.45	22.3
53.5	6.39	22.2
70.3	6.12	20.3
77.75	5.96	20.0

* $\rho_0 = 6.96$; $\alpha_0 = 3.85$; $\beta_0 = 5.42$ [189]. † $\rho_0 = 10.62$; $\alpha_0 = 4.07$; $\beta_0 = 4.73$ [189]. ‡ $\alpha_0 = 3.785$; $\beta_0 = 6.33$.

Co, commercial; *v.* **Co-Fe**

Co-Cu [227]; A_{160}; w = wire, r = rod

Cu	ρ_{20}	α
0.2w	9.73	3.26
9.6r	24.30	1.67
19.5r	16.59	1.66
29.7r	14.79	1.50
40.6r	12.92	1.43
53.4r	11.34	1.32
65.6w	12.10	0.936
76.4w	11.43	0.817
86.8w	10.72	0.776
93.3w	10.02	0.801
96.9w	8.63	0.820
95.9w	9.45	0.771
96.9w	9.45	0.768
98.1w	8.80	0.859
98.5w	6.76	1.084
100.0w	1.672	4.45

Co-Fe [142]; *v. also* **Fe-Co-x**

"Pure cobalt"; 15.5°C; 0.017S; $t_A = 800$*

Fe	ρ_0	ρ_A
0.20	870	
22.5°C; 0.012S, 0.084Si, 0.0066P		
0.19	898	915
"Commercial cobalt"		
21.3°C; 0.023S, 0.09C, tr. Si, tr. Ca		
0.60	2308	
19.6°C; 0.012S, 0.039C, 0.14Si, 0.010P		
1.15	1049	904

* For variation of ρ with t_A, *v.* [142].

Co-Fe-Ni [142]; 21.95°; 0.018S

Fe	Ni	ρ_0
4.49	2.73	1444

Co-Ni [237]

Ni	$\rho_{17\text{ to }18}$	Ni	$\rho_{17\text{ to }18}$
0	6.41	60	10.11
5	6.80	70	11.16
10	7.15	80	11.86
20	7.54	85	11.90
30	8.37	90	11.33
40	9.24	95	10.46
50	9.72	100	7.72

Cu-x [1]; $0 < x < 1$%

x	k	x	k
Ag	6	P*	3000
Al*	500	Pb	3
As*	720	S	8
Au	10	Sb*	190
Bi	4	Si*	70
Cd	9	Sn	67
Fe	140	Te	4
O	25	Zn	30

* For these elements the conductivity concentration curve is markedly curved from the outset, and the values of k have been obtained from a tangent to the curve at zero concentration. These values can therefore only be used for concentrations of a small fraction of 1 %.

Cu-Ag; *cf.* **Ag-Cu**

For Ag, $\rho_0 = 1.54$ Dd wire [186]		1.70% Ag [24]	
Ag	ρ_0	t	ρ_t
1.21	1.77	1100	21.45
		$D = 0.343$	
2.39	1.94	1400	22.48

Cu-Ag-Au; *v.* **Au-Ag-Cu**

Cu-Al; 3% Al [63]; *cf.* **Al-Cu**

t*	ρ_t	t*	ρ_t
−197.1	7.328	+0.85	8.660
−106.1	8.044	16.35	8.990
− 81.9	8.210	92.25	9.575
0.0	8.847	$\alpha_{15} = 0.897$	

* Pt scale of t.

Cu-Al-Ni; *cf.* **Al-Cu-Ni-Fe-Si**

Al [225]	Ni	ρ_A*
5.21	7.31	18.45†
5.32	4.84	15.47†
4.94	2.38	12.56
5.10	0.94	10.88
5.02	0.0	9.85
9.88	2.46	14.40
9.82	1.04	11.74
10.06	0.0	10.27

* t_A = "red" heat.

† ρ is same for $t_A = 900$°C.

Aluminium bronze; *cf.* **Al-Cu** 6.5% Al, 6.5% Ni [63, 76, 212]

t*	ρ_t	t*	ρ_t
−197.1	13.048	+0.9	14.921
−106.1	13.939	16.35	15.066
− 81.9	14.132	91.45	15.785
0.0	14.912	$\alpha_{15} = 0.645$	

* Pt scale of t.

Cu-Al-P (224)

Al	P	$\rho_{11.5}$
4.88	0.20	11.67
4.94	0.09	11.02
4.97	0.06	10.36
5.02	0.0	9.85
9.96	0.11	10.75
10.05	0.05	10.53
10.06	0.0	10.27

Cu-As (221)

As	ρ_0	Δ_{100}
0.25	3.04	2.31
0.5	3.79	2.02
0.75	5.22	1.49
1.0	6.31	1.26
1.5	8.58	0.943
3.0	17.3	0.475
4.0	22.5	0.376
5.0	26.2	0.275
6.0	34.8	0.261
10.0	38.5	0.449
15.0	47.4	0.940
20.0	54.3	1.59
25.0	56.5	2.39
28.5	59.0	2.74
31.2	58.2	2.66
32.3	50.3	2.68
33.1	56.6	2.65
34.9	57.1	2.69
36.5	54.8	2.74
37.8	53.2	2.71
39.4	50.7	2.99
42.0	49.3	2.70

For Cu, $\rho_{18} = 1.78$

As	ρ_{18}
Rod (228)	
1.04	4.92
1.80	7.18
2.66	9.84
2.8	12.6
3.0	11.35
5.02	27.0
5.4	26.85
Sheet (228)	
1.99	4.68
4.83	17.8

For Ag, $\rho_0 = 1.54$; Dd wire (186, 188, 189)

As	ρ_0	α_0	β_0
tr.	2.52	2.64	6.52
2.80	12.51	0.74	0.10
5.40	24.1	0.37	0.04

Cu-As-O (87)

As	O	ρ_t	t
0.05	0.26	2.169	17
0.06	0.3	2.485	18
0.22	0.16	3.178	18
0.4	0.17	3.843	18
0.43	0.42	4.251	17
0.49	0.1	4.690	18

Cu-Au; *v.* Au-Cu

Cu-Au-Ag; *v.* Au-Ag-Cu

Cu-Cd; *v.* Cd-Cu

Cu-Co; *v.* Co-Cu

Cu-Cr; *cf.* Cu-Ni-Cr

Cr (135)	ρ_A	ρ_{Dd}
0	1.697	1.738
0.498	1.788	3.635
0.99	1.832	3.160
4.76	1.986	3.701
6.51	2.404	3.902
9.1	2.209	3.940
13.04	2.324	4.268
14.74	2.52	4.296

Cr (249)	ρ_t	t	α_{20}
4.2	2.084	18.55	3.76
9	2.209	18.7	3.74
13	2.723	22.1	3.44
16.7	3.372	18.75	2.44

Cu-Fe; *cf.* Fe-Cu

A_{1000} in N (236)

Fe	ρ	Fe	ρ
0	1.93	50	6.37
0.5	3.16	60	7.28
0.8	3.36	70	8.63
1	3.36	80	10.10
1.5	3.51	90	11.36
2	3.60	92	11.84
4	3.66	94	12.27
6	3.75	96	13.01
8	3.87	97	14.00
10	3.99	98.5	14.00
15	4.08	99	16.04
20	4.47	99.5	13.70
30	4.99	100	11.84
40	5.77		

Dd wire (186)

Fe	ρ_0	Fe	ρ_0
0.48	4.46	1.05	5.72

Dd, 0.4Fe (188, 189)

ρ_0	α_0	β_0
3.86	1.55	0.33

Cu-Mg (265)

Mg	ρ_{25}	Δ'_{100}
0.56	2.115	3.54
0.65	3.25	2.27
0.77	3.339	2.10
1.53	4.185	1.83
2.97	4.784	1.21
3.28	5.061	1.22
6.75	6.214	1.57
8.76	5.641	2.26
10.06	5.952	2.25
11.65	5.411	2.50
14.53	5.803	2.57
15.38	5.746	2.51
15.47	5.717	2.50
16.05	5.538	2.90
16.28	5.16	3.14

Cu-Mg.—(*Cont'd*)

Mg	ρ_{25}	Δ_{100}
16.46	5.145	3.16
17.71	5.509	3.07
22.66	6.069	2.75
23.7	6.371	3.28
26.7	6.146	2.91
27.55	6.83	2.81
31.9	7.134	3.16
34.4	7.155	3.23
36.35	8.111	3.48
36.8	7.937	3.62
38.15	9.272	3.52
41.11	8.265	
41.12	10.31	3.79
43.3	11.94	3.65
44.5	8.529	3.63
45.0	7.08	3.39
48.0	6.598	3.62
52.9	6.258	3.66
53.05	6.072	3.73
60.2	6.020	3.64
68.8	5.786	3.50
77.5	5.171	3.76
87.8	4.923	3.64

Cu-Mn

[Cu contained: 0.153O, 0.012 Zn, 0.005Fe, 0.003As, 0.003 (Ni + Co), 0.001(Sb + Sn), tr. (Bi + Mn)]; $t_A = 700$°C (198).

Mn	ρ_A	ρ_O
0.04	1.71	1.75
0.07	1.746	1.79
0.12	1.964	2.01
0.29	2.576	2.62
0.40	2.618	2.72
0.61	3.165	3.25
0.98	4.625	4.83
1.34	5.92	6.09
1.49	6.41	6.66

Mn (135)	ρ	α
0	1.697	4.28
4.5	17.9	0.17
7.3	19.7	0.32
12.0	36.7	
40	133	
60	164	

Mn (250)	ρ_{20}	α_{20}
4.2	17.9	0.17
7.4	19.7	0.25

Mn (186)	$\alpha_{0\text{ to }10}$
0.4	0.97
10	0.09
16	0.14

t	20°	22.5°	25°
Mn (147)	$(10^6/\rho_0)(d\rho_0/dt)$		
12	9.09	6.71	4.31
13	8.92	3.48	0.84
14	4.47	1.68	1.12
15	3.93	1.04	1.85

Cu-Mn.—(*Cont'd*)

α, 20 to 100°C (148)

Mn	ρ_{20}	α_{20}
15	50	0.02

Mn (147)	$\rho_{22.5}$	$\alpha_{22.5}$
13	45	0.00348

Cu-Mn-Al (65)

(Therlo) t = 20 to 100°C

Mn	Al	ρ_{20}	α_0
13	2	46.5	0.01

Cu-Mn-Fe (147)

Mn	Fe	$\rho_{22.5}$
10.17	0.286	32.57
12.69	0.329	42.78
14.76	0.327	53.46
18.55	0.401	64.54
Resistin (160)		
13.5	1.9	50.2

Cu-Mn-Fe-Si

Mn	Fe	Si	ρ	α
12.3	0.54	0.26	43.9	
24.95	0.34	0	81.2	0.05
30.0	1.32	0.11	107.3	0.04

Cu-Mn-Ni-(Fe)

Manganin; *v. also* Cu-Ni-Mn and Cu-Ni-Fe-Mn

12% Mn, 4% Ni

t	ρ_t
(63)	
91.6	47.528
16.25	47.640
+ 0.9	47.636
− 81.9	47.387
−106.1	47.225
−197.1	45.820
−217	45.275
(169)	
+ 17.7	44.6
−164.0	43.0
−163.0	43.0
−154.5	43.1
−145.3	43.2
−133.6	43.4
−119.2	43.9
− 98.5	44.2
− 66.8	44.4
− 50.2	44.5
− 43.6	44.5
− 14.0	44.5
+ 13.8	44.5
(144)	
18	42.0

12% Mn, 3% Ni; 0 to 10°C

$\alpha = 0.14$ (90)

Mn (73)	Ni	ρ	α
24	3	47.7	−0.03
30	0	100.6	+0.04

Cu-Mn-Ni-(Fe).—(*Cont'd*)

Mn (131, 234)	Ni	Fe	ρ_{20}	α
8.84	1.78	0.93	55.6	0.0033
9.93	1.74	0.24	34.2	0.012
10.26	1.77	0.52	37.4	0.015
12.03	3.41	1.04	47.8	0.0022
12.83	2.08	0.73	50.8	0.0038
12.93	2.60	0.82	51.1	0.0057
13.5	2.5	0	37.4	0.016

Other data by (2, 65, 66, 141, 144, 201). Manganin, composition not stated.

ρ_{15}	α (2)
Wire	
42.9	−0.024*
41.0 to 43.2	−0.010†
Sheet	
46.0	−0.014*
44.8	−0.008†

* Range 15 to 97°C.
† Reichsanstalt; range 17 to 53°C for wire, 18 to 60° for sheet.

t (260)	α
12.6	+0.006
25	0
50	−0.020
75	−0.035
100	−0.042
125	−0.047
150	−0.050
175	−0.050
200	−0.050
225	−0.050
250	−0.052
275	−0.060
300	−0.057
325	−0.040
350	−0.015
375	+0.010
425	0.040
400	0.060
450	0.055

Cu-Mn-Ni-(Fe).—(*Cont'd*)

t (260)	α
475	0
500	−0.110
525	0
550	+0.150

ρ_0 = 38.79; Δ_{100} = 0.015 (201).

Effect of hydrostatic pressure (31). Composition of the commercial manganin is not given.

r_0, $[r_p]$ = resistance for p = 0, $[p = p]$; $\Delta = 10^9(r_p - r_0)/r_0 p$; unit of p = 1 kg/cm².

p	Δ	p	Δ
1260	2272	9290	2302
2610	2282	8000	2304
3810	2299	6450	2302
5000	2301	4790	2304
6180	2299	3250	2291
7210	2300	1740	2308
8230	2302	1000	2272

Cu-Ni; *cf.* **Cu-Ni-Fe-Mn**, and Table 3

α, 20 to 100°C (86)

Ni	ρ_{20}	α_{20}
0	1.67	4
10	14.6	
20		0.26*
30	38.5	
40	49	
48	49	0.018†
57.5	50.3	0.005
68	50	
100	7	4
	(91)	
2	3	
20	28	
43‡	45.0	0.01
46§	50.2	
50	51	

* 0.110 (162). † CuNi, from (135).
‡ From (148).
§ From (93), t = 0°C.

Cu-Ni.—(*Continued*)

0 to 370°C (214)

Ni	Co	Fe	ρ_0	α	β
9	0.5	1	22	0.570	0.23
20	0	tr.	27.26	0.326	0.69
30	0	tr.	32.35	0.270	0.37
40*	0	0	42.39	0.167	0.047

* 40 % Ni = Constantan.

α, 40 to 70°C (244)

Ni	ρ_t	t	α_0
3.94	9.0	38.8	1.46
17.3	26.3	54.9	0.30

Named alloys:

Key	Name
Ae	Advance, *v. also* **Cu-Ni-Fe-Mn**
Cn	Constantan, *v.* also **Cu-Ni-Mn**

Named alloys.—(*Cont'd*)

Key	Name
Cl	Copel
	Eureka = Constantan
Ia	Ia-Ia
Il	Ideal
PN	Patent nickel, *v. also* **Cu-Ni-Fe-Zn-Mn**
Re	Rheostatine

Cu-Ni.—(*Continued*)

ρ	α	Lit.
	25% Ni; PN	
33.5	0.2	
	40% Ni; Cn, Ia	
47–51	−0.04–(+0.03)	(40, 66, 141, 144)
	45% Ni; Ae, Cl, Il	
49–49.5	Nil.–0.01	(65, 130)
	48% Ni; Ae, Cn, Ia, Re	
47–49	0.005–0.25	(135)
Composition not given (66, 141, 201); *cf.* (10, 160, 260)		
44–50	−0.057–(+0.11)	Cn
47–48	0.25–0.27	Re

Cu-Ni.—(*Cont'd*)

Ia-Ia (260)

t	α	t	α
12.5	0.033	275	0.029
25	0.030	300	0.035
50	0.022	325	0.030
75	0.015	350	0.030
100	0.006	375	0.028
125	0.006	400	0.028
150	0.005	425	0.035
175	0.009	450	0.067
200	0.010	475	0.110
225	0.015	500	0.200
250	0.020		

Cu-Ni-Al; *v.* **Cu-Al-Ni**

Cu-Ni-Co-Fe-Zn; *v.* **Cu-Ni-Fe-Co-Zn**

Cu-Ni-Cr (135, 250)

Ni	ρ_{20}	α
4.76% Cr		
0	2.1	3.45
23.84	25.1	0.35
47.62	55.1	0.14
71.4	70.5	0.41
95.24	45.7	0.97
9.1% Cr		
0	2.2	3.49
22.7	22.4	0.42
45.45	50.7	0.18
68.2	83.9	0.16
77.3	86.3	
90.9	67.8	0.37
13.04% Cr		
0	3.4	2.5
21.76	22.1	0.47
65.2	86.4	0.11
73.9	99.0	
78.2	95.7	
86.96	84.1	0.20
16.7% Cr		
0	2.7	2.99
20.8	21.3	0.46
41.6	36.7	0.31
62.5	86.3	0.12
66.7	108.7	
70.8	109.8	
70.8	112.9	0.078
75	106.4	
75	106.3	0.079
79.1	98.3	

Cu-Ni-Cr.—(*Cont'd*)

Ni	ρ_{20}	α
16.7% Cr		
83.3	95.9	
83.3	96.9	0.12
20% Cr		
64	121.8	
67	110	
67	111.6	
72	107	

Ni (249)	Cr	ρ_t	t	α
62.5	16.7	86.3	18.2	0.12
65.1	13.15	86.4	20.6	0.11
68.2	9.1	83.9	18.6	0.16
71.4	4.8	70.5	22.6	0.41
82	12	85*		0.3*

* From (148).

Cu-Ni-Fe-x

Excelsior (66, 141)

Cu, 53; Ni, 45; Fe; x

ρ_0	α at 17°
II 5.79	1.42
I 80.29	0.95

Cu-Ni-Fe-Co; *v.* **Cu-Ni**

Cu-Ni-Fe-Co-Zn

Silverine (63)

Ni = 17%, Fe = Co = Zn = 2%

t*	ρ_t
−197.1	0.909
−106.1	1.452
− 81.9	1.582
0.0	2.064
+ 0.95	2.071
16.25	2.166
+ 90.9	2.614
α_{15} = 2.85	

* Pt-scale of t.

Cu-Ni-Fe-Mn; *v. also* **Cu-Ni-Fe-Mn-(Si, C)**

Ni (155)	Fe	Mn	ρ_0	α_0
0.00			1.53	3.77
10.04	0.15	tr.	14.6	0.49
16.01	0.18	tr.	21.6	0.31
20.04	0.13	tr.	26.4	0.27
24.07	0.58	0.02	31.3*	0.21
29.94	0.36	0.36	38.4	+0.12

Cu-Ni-Fe-Mn.—(*Cont'd*)

Ni (155)	Fe	Mn	ρ_0	α_0
41.25	0.37	0.70	50.0	−0.032
46.18	0.32		52.2	−0.080
49.36	0.54	0.32	51.7	+0.040
50.84	0.38	0.65	51.7	0.055
56.37	0.34	tr.	52.5	0.15
62.02	0.34	tr.	51.5	0.16
89.46	1.19	1.40	19.0	3.00
93.66	1.02	1.45	16.6	2.90
100.00			12.3	3.47

* 0.70 % Zn.

Advance (65, 134, 260); *v. also* **Cu-Ni**

Ni	Fe	Mn	ρ_{20}	α
44	0.5	1.0	48.8	*ca.* 0.01
44	0.45	1.16	48.2	0.02

t (134)	ρ	t (134)	ρ
20	48.24	400	48.51
100	48.20	500	49.20
200	48.22	600	50.11
300	48.31		

t (260)	α	t (260)	α
12.5	+0.020	300	0.027
25	+0.005	325	0.030
50	−0.008	350	0.030
75	−0.012	375	0.033
100	−0.007	400	+0.025
125	−0.004	425	−0.010
150	0	450	+0.020
175	+0.003	475	0.040
200	0.007	500	0.080
225	0.010	525	0.105
250	0.014	550	0.105
275	0.020		

Cu-Ni-Fe-Mn-(Si, C), Monel metals

67Ni, (Fe + Mn + Si) = *ca.* 5 (136)

t	ρ	t	ρ
20	44.68	100	51.4
30	45.57	110	51.8
40	46.53	120	52.2
50	47.50	130	52.5
60	48.45	140	52.86
70	49.4	150	53.1
80	50.3	160	53.32
90	50.9		

ρ_{20}	α_{20}
43.5	0.022
44.9*	1.9*

* From (65).

68.10Ni, 2.4Fe, 1.5Mn, 0.11Si, 0.16C (134)

t	ρ	t	ρ
20	44.56	600	61.70
100	51.69	700	63.92
200	54.13	800	66.16
300	55.91	900	69.05
400	57.70	1000	72.65
500	59.70		

ρ = 42.6; α = 1.98 (207).

68Ni, 2.5Fe, 1.5Mn (65)

ρ_{20}	α_{20}
42.5	1.9

Cu-Ni-Fe-Zn-Mn (73, 74), Patent nickel; *v. also* **Cu-Ni**

Ni	Fe	Zn	Mn	ρ	α
24.14	0.70	0.52	0.17	32.8	0.21
25.1	0.42	0.23	0.13	34.2	0.19

Cu-Ni-Mn (250)

Ni	ρ_{20}	α_{20}
4.8% Mn		
0	17.9	0.17
19.0	33.5	0.14
38.1	50.4	0.089
47.6	55.1	0.085
57.1	54.35	0.22
66.6	50.72	1.09
76.2	38.8	2.39
95.2	17.4	2.97
7.4% Mn		
0	19.7	0.32
18.5	40.2	0.075
37.0	54.8	0.071
46.4	58.1	0.088
55.5	60.05	0.14
64.8	55.8	0.53

Cu-Ni-Mn.—(*Cont'd*)

Ni	ρ_{20}	α_{20}
7.4% Mn		
74.1	45.8	1.85
92.6	23.3	2.49
13.1% Mn		
26.1	62.1	−0.026
34.8	68.7	−0.016
43.5	70.8	+0.025
52.1	75.3	+0.064

40–55Ni, 0–1.4Mn, 0.1C (Constantan); *v. also* **Cu-Ni**

t (245)	ρ/ρ_0
0	10 000
− 76.4	9 982
−185.8	9 898
−252.9	9 784

Cu-Ni-Mn.—(*Cont'd*)

t (260)	α
12.5	+0.008
25	+0.002
50	−0.014
75	−0.028
100	−0.033
125	−0.033
150	−0.030
175	−0.027
200	−0.020
225	−0.020
250	−0.017
275	−0.015
300	−0.015
325	−0.013
350	−0.012
375	−0.007
400	0
425	+0.007
450	0.014
475	0.017
500	0.027
525	0.047
550	0.100

Cu-Ni-Mn.—(*Cont'd*)

65Ni, 5Mn (Lucero) (65); ρ_{20} = 46.6; α = 0.76

67Ni, 2.60Mn (112); for t_A = 650°, Δ_H = 7.7

Cu-Ni-Mn-Fe; *v.* **Cu-Ni-Fe-Mn**

Cu-Ni-Ti, Wire (132)

Ni	Ti	ρ
16	1	23
41	2	52.5
22	3	31.5
48.5	3	53.3
62*	3	63.2
73	3	61.7
40	4	51.7
55	4	58.7
71	5	60.3

* For 63 % Ni, α = 0.267.

Cu-Ni-Zn (112); *v. also* **Ni-Cu-Zn** and **Cu-Ni-Zn-(Co, Fe, Mn)**

t_A = 650°C

Ni	Zn	Δ_H
13	20.3	−1.5
23.24	18.9	+6.7

Cu-Ni-Zn-(Co, Fe, Mn)

German silvers; t = 15 to 17°C; t_A = 797°C; 55–62% Cu (276)

Ni	Zn	Mn	ρ_H	ρ_A	Key
28.6	9.8	0.0	41.5	41.3	**A**
22.4	15.85	0.0	32.6	34.0	**B**
16.4	21.7	0.0	30.2	29.8	**C**
17.4	26.7	0.0	27.5	27.6	**D**
7.62	31.7	0.0	22.2	19.2	**E**
27.9	11.4	0.25	38.5	39.1	**F**
19.8	18.5	0.25	29.5	31.5	**G**
15.5	23.2	0.25	27.5	28.0	**H**
15.75	29.7	0.25	27.7	28.3	**I**
7.80	31.8	0.25	18.3	17.2	**J**
26.7	13.15	1.5	38.5	39.8	**K**
16.3	27.6	1.5	30.4	31.8	**L**

Variation with t_A

Key	A	B	C	D	E
t_A	ρ_A (Mn = 0)				
100	41.6	32.8	30.5	27.7	21.6
245	41.6	32.3	30.0	27.9	22.0
293	42.0	32.5	30.4	28.0	21.1
332	42.2	33.8	31.5	28.6	20.7
353	41.7	34.2	31.5	28.4	19.3
381	41.5	34.5	31.8	28.0	18.8
405	40.9	32.6	30.6	27.5	18.3
430	40.9	32.5	30.0	27.4	18.2
453	41.0	33.5	30.5	26.8	17.9
470	40.9	33.9	30.0	27.5	18.3
500	41.0	33.0	30.1	27.0	18.4
538	40.9	33.5	30.5	27.3	18.6
590	40.9	33.9	30.8	27.7	19.0
646	41.1	33.1	30.3	27.1	19.5
696	41.1	33.5	30.4	27.5	19.5
797	41.3	34.0	29.8	27.6	19.2

Cu-Ni-Zn-(Co, Fe, Mn).—(*Continued*)

Key	F	G	H	I	J
t_A	ρ_A (Mn = 0.25)				
100	38.0	29.5	27.2	27.5	18.2
245	38.4	29.3	27.7	27.7	18.2
293	38.5	30.1	27.8	28.4	18.0
332	39.0	30.9	29.0	29.5	18.1
353	39.0	31.7	29.1	29.5	17.7
381	38.9	31.9	29.0	29.5	16.6
405	39.0	32.0	28.2	28.3	16.5
430	38.3	29.6	28.1	28.0	16.7
453	38.5	31.8	28.1	28.1	16.7
470	38.8	32.2	27.9	27.5	16.7
500	38.7	31.6	27.2	28.3	16.9
538	38.6	32.0	27.7	28.1	16.6
590	39.0	32.4	27.9	28.6	16.8
646	38.8		27.8	28.0	16.6
696	38.7	31.5	27.7	28.0	16.6
797	39.1	31.5	28.0	28.3	17.2

Key	K	L	Key	K	L
t_A	ρ_A (Mn = 1.5)		t_A	ρ_A (Mn = 1.5)	
100	38.1	29.5	453	39.5	31.5
245	38.9	30.5	470	39.5	31.1
293	38.0	30.7	500	40.0	30.8
332	39.0	32.5	538	39.4	31.0
353	39.5	32.8	590	39.2	31.5
381	39.5	33.2	646	39.8	31.4
405	39.6	32.1	696	39.8	30.9
430	39.6	31.0	797	39.8	31.8

50% to 63% Cu; Argentan (A), German silver* (G), Maillechort (M), Nickeline* (N), Nickel silver (S), Platinoid (P), Rheotan (R); approximately 62Cu, 22Zn, 15Ni (153)

German silver				Platinoid			
t	ρ	t	ρ	t	ρ	t	ρ
+ 17.2	39.8	−116.1	38.3	+ 21.2	34.4	−99.5	33.1
−169.1	38.0	−105.3	38.4	−171.0	32.4	−96.4	33.1
−168.2	38.0	− 95.5	38.6	−173.0	32.3	−92.1	33.3
−159.3	38.0	− 57.2	39.0	−172.0	32.4	−71.0	33.3
−153.0	37.9	− 53.3	39.1	−160.2	32.3	−66.6	33.5
−145.8	37.9	− 50.9	39.1	−155.0	32.4	−35.0	33.7
−134.6	38.0	− 16.0	39.5	−146.7	32.6	−24.4	33.8
−126.9	38.1	+ 16.5	39.8	−134.6	32.8	+10.0	34.3
				−103.9	33.0	+10.5	34.3

* German silver, ρ_0 = 42.9, α_0 = 0.038; Nickeline, ρ_0 = 27 to 43, α_0 = 0.024 to 0.34; composition not stated (66, 141).

	Ni	Zn	Fe	Mn	ρ_0	α_0	Lit.
G	15	22			26.6	0.38	(144)
P	15	22			34.2	0.32*	(169)
GM	14	25	0.3		30.0	0.36	(73, 74)
N	18.5	20	0.24		33.2	0.30	(73, 74)
G	18.5	31.1			30.0	0.27	(63); *cf.* (76)
N	24.5	20.4	0.64		44.8	0.33	(73)
N					36.2	0.22	(201)
P	25	20.4	0.5	0.15	41		(160)
R	25	16.9	4.46	0.37	52.5	0.41	(73)
R	25	17	5		47.6	0.24	(66, 141)
R					44.65	0.28	(201)
A	26	18	(t = 15°)		42.0		(65)
A					28.45	0.33	(201)
S	18	27	(t = 20°)		30	0.27	(65)
S	18	(?)	(t = 20°)		33	0.31	(135)

* From 0 to −173°C. For wire, ρ_{18} = 34.4, α_0 = 0.25 for 18 to −160°C (144); *cf.* (141, 166).

Cu-Ni-Zn(Co, Fe, Mn).—(*Continued*)

40% to 56% Cu, German silvers; 0 to 370°C (214)

Ni	Zn	Fe	Co	ρ_0	α_0	β_0
32	16			25.26	0.26	1.3
23	19		tr.	22.52	0.28	5.2
18	24		2	30.87	0.043	0.28
30	26	tr.	4	47.61	0.043	0.80

Cu-P

[Cu contains: 0.153O, 0.012Zn, 0.005Fe, 0.003As, 0.003(Ni + Co), 0.001(Sb + Sn), tr. (Bi + Mn)]; t_A = 700°C (198).

P	ρ_O	ρ_A
0.011		1.71
0.040	2.09	2.12
0.092	2.51	2.508
0.173	3.07	3.237
0.399	5.23	5.59
0.563	7.24	7.94
1.062	12.66	13.32

For Cu, ρ_{18} = 1.78 (228)

P	ρ_{18}	P	ρ_{18}
Rod		Sheet	
0	1.78	0	1.78
0.13	2.45	0.30	3.27
0.34	4.85	0.76	6.12
0.87	8.55	1.19	8.36
1.79	13.7	1.56	9.95
2.35	17.6	1.73	10.53
2.5	22.9	3.15	20.2
5.25	31.8		

For Ag, ρ_0 = 1.54; Dd wire (186, 188, 189)

P	ρ_0	α_0	β_0
0.13	2.28		
0.95	6.59	1.32	0.10
2.5	20.84	0.48	0.04

Cu-Pb; *v.* Table 3

Cu-Sb; *v. also* Table 3

Sb	ρ	(96)
48.6	8.3	Cu_2Sb
65.4	20	CuSb

Cu-Sb-O (87)

Sb	O	ρ_{18}
0.14	0.08	1.86
0.13	0.27	1.87
0.18	0.31	1.93
0.39	0.10	2.60

Cu-Sn; *v. also* Table 3

Bronze, 12% Sn; *v. also* **Cu-Sn-Zn-Pb** (167, 172)

Sn	ρ_0	Δ_{100}
4.1	8.2	1.08
8.3	10.4	1.14
9.7	15.5*	0.109†
12.6	18.0	0.8
12.6	17.3*	

Cu-Sn.—(*Cont'd*)

Sn	ρ_0	Δ_{100}
17.2	21.7	+0.51
21.4	29.4	−1.49
25.95	32.5	−0.03
30.15	41.8	+0.46
31.7	48.3*	
35.3	15.32	1.32
38.2	11.12*	
40.1	8.75	2.82
44.9	11.1	2.7
50.0	12.2	2.15
55.1	11.7	2.4
60.25	12.1	2.42
65.6	12.95	2.76
71.1	13.3	2.96
77.5	13.4	3.84
80.8	13.15*	
82.2	12.9	3.54
88.1	12.8	3.07
94.0	12.4	4
100.0	12.8	4.5
100.0	12.0*	

* From (172). † For 10% Sn (162).

[Cu contains: 0.153O, 0.012Zn, 0.005Fe, 0.003As, 0.003(Ni + Co), 0.001(Sb + Sn), tr. (Mn + Bi)]; t_A = 700°C (198)

Sn	ρ_A	ρ_O
0.13	1.955	2.01
0.24	2.096	2.16
0.32	2.459	2.47
0.40	2.542	2.57
0.53	2.542	2.61
0.62	2.73	2.86
0.88	2.96	3.00
1.15	2.99	3.09
1.24	3.495	3.5
1.46	3.645	3.74

Dd wire (186); For Ag, ρ_0 = 1.54

Sn	ρ_0
1.31	3.17
2.46	4.72
4.67	7.91

Sn	ρ_t	t	Lit.
5.	10.11	49.6*	(244)
38.5	33.3	Cu_4Sn	(96)
48.3	11.1	Cu_3Sn	(96)
65.1	13.3	CuSn	(96)
7.3	Δ_H† = +4.1%		(112)

* α_0 = 1.06, 50 to 90°C.
† t_A = 675°C.

Cu-Sn.—(*Cont'd*)

Sn (188, 189)	ρ_0*	α_0	β_0
1.15	2.45	2.68	2.14
5.16	7.77	1.00	0.29
8.91	12.63	0.76	+0.24
9.55	15.08	0.67	−0.74
12.5	17.24	0.55	+0.005
80.6	11.81	3.33	6.85
92.2	12.52	3.68	5.44

* Assumes for Ag, $\rho_0 = 1.54$.

Cu-Sn-P (217)

Sn	P	ρ_A	ρ_{T_D}
5.08	0.01	10.5	10.5

Phosphor bronze wire

Sn	P	ρ_0	α_0
2	(?)*	5 –6	
0.2	(?)*	1.7–2	3–4

* Content not stated.

Cu-Sn-Pb (186)

Sn	Pb	ρ_0
0	0	1.835
0.1	0	1.70
0.1	0.1	1.72

Cu-Sn-Si, Silicon bronze wire

Sn	Si	ρ_0	α_0
1.5–9	0.05	1.7–3.9	2.3–3.8

Cu-Sn-Zn-Fe-(P), 0.01% P (217)

Sn	Zn	Fe	ρ_A	ρ_{T_D}
14.42	tr.	0.06	20.2	21.2
10.02	0.21	0.05	15.8	16.6

Sn (202, 216)	Zn	Fe	P	ρ_A	ρ_{T_D}
5.08	0	0	0.01	10.5	10.5
10.02	0.21	0.05	0.01	15.8	16.6
14.42	tr.	0.06	0.01	20.2	21.2
19.16	0.43	0.13	0	25.9	27.0

Cu-Sn-Zn-Pb, Bronze; *v. also* Cu-Sn

Sn	Zn	Pb	ρ_{15}
6	4	1	13.5

Cu-Ti wire (132)

Ti	ρ	α
1	22.38	0.29_2
2	35.51	2.14_0
5	57.2	

Cu-Zn, for molten alloy, *v.* Table 3

Zn	ρ_0	Δ_{100}
	(222)	
0	1.538	4.43
3.15	2.392	3.02
5.2	3.188	2.34
8.3	4.029	2.14
30.6	6.866	1.60

Cu-Zn.—(*Cont'd*)

Zn	ρ_0	Δ_{100}
32.2	7.029	1.59
35.65	6.957	1.63
38.65	6.808	1.71
42.7	5.558	2.51
43.7	5.420	2.65
45.7	4.682	3.00
48.7	4.291	3.39
50.0	4.137	3.57
50.7	4.330	3.55
50.7	4.302*	3.64
53.7	6.000†	3.16
58.7	11.28	2.22
59.7	13.01	2.08
60.7	12.10	2.34
61.7	11.31	2.50
62.65	11.00	2.54
65.65	10.25	2.90
65.65	10.30	3.00
67.35	9.812	4.08
69.6	9.533	3.57
70.6	9.226	3.61
71.6	8.597	3.31
72.6	8.460	3.02
72.6	8.252	3.22
75.55	8.050	2.74
77.55		2.53
78.5	7.491	2.42
80.5		2.42
81.5	6.864	2.57
83.45	8.972	2.77
84.4	10.42	3.07
85.4	11.56	3.20
86.1	11.75	3.51
86.4	10.71	3.29
86.85	9.704	3.20
88.3	7.451	
89.3	7.100	3.25
90.25	6.555	3.58
91.35	6.362	3.47
92.2	6.420	3.44
93.2	6.419	3.50
95.15	6.403	3.58
97.1	6.306	3.79
100.0	6.154	4.27
	(202)	
2.48	2.675	2.92
7.45	3.875	1.891
11.65	4.51	1.862
15.0	4.92	1.869
19.05	5.74	1.852
26.8	6.08	1.767
28.75	6.16	1.750
34.15	6.72	1.676
36.3	6.8	1.474
42.1	5.875	1.635
47.5	4.52	2.320
53.8	5.28	1.933
57.7	11.8	2.086
63.3	8.1	1.754
68.9	8.62	3.341
75.3	8.54	2.615
76.3	7.67	1.793
82.4	8.17	2.51

Cu-Zn.—(*Cont'd*)

Zn	ρ_0	Δ_{100}
88.25	7.65	2.778
92.25	6.08	3.351
93.8	6.2	3.361
	(117)	
0	1.576	4.316
0	1.592	4.328
0.71	1.823	3.725
1.56	2.133	3.185
3.07	2.372	2.913
5.51	3.010	2.383
9.08	3.628	2.044
18.02	4.763	1.691
20.29	5.064	1.639
22.71	5.424	1.607
28.16	5.826	1.581
34.23	6.302	1.579
40.28	5.789	2.116
42.55	5.307	2.376
45.19	4.712	2.851
46.85	4.314	3.105
99.53	5.883	3.847
100.00	5.683	4.029

* CuZn; Guertler (96) gives $\rho = 3.1$.
† For 55.7 % Zn, $\rho_{25} = 8.181$.

Zn (244)	ρ_t	t	α_0*
3.11	2.84	41.5	3.06
5.00	3.83	38.5	2.72

* 40 to 70°C.

Zn (188, 189)	ρ_0*	α	β
4.05	2.54	2.471	2.01
8.89	3.26	2.04	1.56
19.8	5.43	1.42	0.65
25.0	6.98	1.27	0.38
36.7	6.91	1.37	0.55

* Assumes for Ag, $\rho_0 = 1.54$.

Brass rod, Zn = *ca.* 30%, D = 1.40 if $-180° < t < 22°$ (169)

Brass wire, Zn = 33%, Δ_{Hm} = 5.7; $\rho_A = 6.61$; $\rho_{Hm} = 6.99$ (111)

Brass (112); t_A = 650°C

Zn	Δ_H	Zn	Δ_H
8.3	+ 3.6	32.1*	+21.8
18.2	+11.4	39.7	+16.5

* Δ_H varies from 6.5 to 21.8 % depending upon the amount of hardening.

Cu-Zn-Fe; t = 20°C

Zn	Fe	ρ_A	Lit.
39.52	0.13	6.30	(113)
49.8	0.13	5.0*	(217)

* t_A = 650°C. Cast = 4.6, Q_{750} = 5.8.

Cu-Zn-Ni; *v.* Cu-Ni-Zn

Cu-Zn-Ni-(Co, Fe, Mn); *v.* Cu-Ni-Zn-(Co, Fe, Mn)

Cu-Zn-Pb (113); *v. also* Table 3

Zn	Pb	ρ_A	ρ_{R_0}
31.86	0.13	6.47	7.88*

* Drawn to 1.5 mm and cold rolled to sectional area = 1.17 mm²; previous annealing reduces effect of rolling.

Fe; $\rho_{18} = 9.66$ (146)

For effect of stress and of magnetic field, *v.* **Fe-Ni**

Fe-*x*

The substance x is indicated by its symbol; t = 18°C; Gh = Gumlich, Bs = Benedicks, Bt = Barrett, Mr = Mahler; all as quoted by Stäblein (262).

δ		Lit.
	Al	
δ_1	11.6	Gh
	11.8	Bs
	14	Bt
δ_2	28	(9)
	25.5	(13)
δ_3	36	(9)
δ_4	44.5	(13)
δ_5	54	(9)
δ_6	61.5	(13)
	B	
δ_1	6.2	(298)
	C*	
δ_1	− 1.74	(146)
	+13.3	(298)
	Dissolved C	
δ_1	3.4	Gh
	0.0	Bs
	(5)	Bt
	7	Mr
	Free C	
δ_1	29	Gh
	26.8	Bs
	Cr	
δ_1	6.2	Bs
	5	Bt
δ_2	10	(9)
δ_3	11.5	(9)
δ_4	12.0	(13)
δ_5	14	(9)
δ_6	14.0	(13)
	Cu	
δ_1	− 0.18	(146)
	+ 5.5	Gh
	5.1	Bs
	4	(45)
	4	(236)
	Mn*	
δ_1	6.27	(146)
	4.7	Gh
	5.9	Bs
	8	Bt
	5	Mr
	5.5	(178)
δ_2	16	(9)
	15.0	(13)
δ_3	18	(9)
δ_4	21.0	(13)

Fe-*x*.—(*Cont'd*)

δ		Lit.
Mn.*—(*Cont'd*)		
δ_5	24.5	(9)
δ_6	26.0	(13)
Ni		
δ_1	1.46	(146)
	5.5	Bs
	3.5	Bt
	1.7	(123)
δ_2	7	(9)
	6.5	(13)
δ_3	9	(9)
δ_4	10.0	(13)
δ_5	13	(9)
δ_6	12.5	(13)
P*		
δ_1	10.69	(146)
	11.2	Gh
	10.3	Bs
	11.0	(4)
S*		
δ_1	1.80	(146)
	10.9	Gh
	10.0	Bs
Si*		
δ_1	20.26	(146)
	13.3	Gh
	11.3	Bs
	13	Bt
	13†	(299)
	11†	(299)

Fe-*x*.—(*Cont'd*)

δ		Lit.
Si.*—(*Cont'd*)		
δ_2	26	(9)
δ_3	34	(9)
δ_4	41.0	(13)
δ_5	49	(9)
δ_6	55.5	(13)
W		
δ_1	1.75	Bs
	2	Bt
δ_2	4	(9)
	4.0	(13)
δ_3	5	(9)
δ_4	5.5	(13)
δ_5	6	(9)
δ_6	6.0	(13)

* If symbol of *x* indicates the Wt. %, then for C ≲ 0.02, Mn ≲ 1, P ≲ 0.015, and S ≲ 0.1, $\rho_{20} = 9.6 + 7Mn + 12S + 60P + 82.5C$; for Si ≲ 0.35, $\rho = 9.6 + 18.4$ Si, for 0.35 ≲ Si ≲ 6.5, $\rho = 16.05 + 11.1$ (Si − 0.35) (303, 304).

† 11 to 13.

Fe-(C, Mn, P, S, Si)

If C_i = Wt. % of total impurities, then, roughly, $\rho = 8 + 7.5C_i$ if C_i lies between 0.4 and 1.9; deviations of 15% or 20% are recorded (52).

Fe-(P, S, Se, C)

Elec. Fe; 1/1000 % (305)

S	C	C*	ρ_A	t_A	
	3		10.25	920	vac
	16	4	9.91	905	vac
17			9.93	950	air
10	25		10.15	950	
19	14	8	10.28	910	vac
13	20	16	10.81	910	vac
10	30	21	11.43	910	vac
12	76	61	11.47	920	vac
S	P	C*	ρ_A	t_A	
35			10.3	923	vac
36			10.4	923	vac
40			10.3	923	vac
60			10.65	923	vac
68			10.55	923	vac
28			12.55	922	vac
29			11.34	922	vac
36			11.0	922	vac
21	10		10.8	924	vac
16	19	0.8	10.35	924	vac
23	33	1.5	10.45	924	vac
20	37	1.1	10.8	924	vac
20	41	1.6	10.85	924	vac

* After annealing.

Fe-(P, S, Se, C).—(*Cont'd*)

1/1000 % (46)

Se	17	19
ρ_{Tp}	16.2	14.6
	t_{Tp} = 900°C	

Fe-Ag (46); t_{Tp} = 900°C

Ag	ρ_{Tp}
0.281	12.5
0.492	13.3
0.506	13.6
0.533	13.1
0.581	14.7
0.677	13.5
0.691	13.8
4.0	7.7*

* A_{1000}; ρ_{Hm} = 12.2.

Fe-Al

At 18°C, $\delta_2 = 23$, $\delta_3 = 36$, $\delta_5 = 54$ (9)

Al	ρ
A_{1100}; 20°C; C ≲ 0.16% (306)*	
0	10.3
0.09	11.0
0.1	11.8
0.73	18.0
1.55	29.4
3.31	43.9
3.53	49.0
4.83	57.7
5.30	67.7
8.10	81.4
8.60	84.3
Treatment (?) (158.1)	
10	100
Tp_{900} (46)	
0.067	23.9
1.333	17.4
0.8% Al	
ρ_{Hm} = 20.6	
ρ_A = 16.1	
t_A = 1000°C	

* ρ is unaffected by heat treatment; same for F, A_{900}, and A_{1100}; C ≲ 0.06 %, excepting for Al = 4.83, 8.10, 8.60, for which C = 0.16, 0.09, 0.13 %, respectively.

Fe-Al-C

Al	C	ρ_N
t = 20 to 23°C; t_H = 975°C		
$\rho_H - \rho_N$ = *ca.* 1.0 (219)		
0.51	0.09	17.1
1.08	0.11	26.3
2.04	0.17	35.9
3.05	0.13	50.7
5.08	0.17	63.6
7.18	0.08	76.6
t = 19 to 23°C; t_H = 975°C		
$\rho_H - \rho_N$ = *ca.* 10		
1.05	0.67	30.3
2.09	0.80	47.4
2.89	0.69	53.0
4.65	0.81	65.6
9.15	0.66	92.6
14.90	0.87	87.8

Fe-Al-Cr-C (12, 13)

t = 18°C; t_A = 1000°C

Al	Cr	C	ρ_A	ρ_O
0.75	1.75	0.21	28.0	33.2
1.00	3.50	0.46	45.0	49.9
2.50	1.50	0.18	50.3	58.5
4.50	1.50	0.22	68.4	77.8
$\rho_O - \rho_A$ = *ca.* 0.15ρ_A				

Fe-Al-Si-C (12, 13)

t = 18°C

Al	Si	C	ρ_A	ρ_O
0.75	0.10	0.17	22.0	24.8
2.25	0.18	0.24	39.0	46.3
5.50	0.20	0.22	70.0*	71.8

* ρ_D = 74.6; α_D = 0.63 for 0 to 150°C.

Fe-Al-Sn (46)

Al	Sn	ρ_A*	ρ_{Hm}
2	1	18.2	18.9

* t_A = 1000°C.

Fe-As(46)

As	ρ
Tp_{900}	
0.292	14.7
0.430	16.8
0.915	19.5
1.81	25.5
3.862	37.1
3.563	34.0
A_{1000}	
1.0	14.3
3.0	26.1
5.0*	20.8
Hm	
1.0	18.1
3.0	25.3
5.0	26.7

* Adding 5 % As to transformer iron (A_{1000}) increases ρ from 18.7 to 30.2.

Fe-As-Mn-Cu-P

0.4Mn, 0.2Cu, 0.2P, 0.05S, 0.05Si, 0.08C (170)

As	ρ
0.123	13.3
0.277	14.2
0.405	15.3
0.459	15.8
0.691	16.8
0.880	18.4
1.172	20.6
1.425	21.9
1.621	23.4
1.943	25.2
2.240	27.3
2.534	27.5
2.841	29.1
3.130	31.6
3.284	37.9
3.515	35.3

Fe-Au (102); *v. also* **Au-Fe** and figure on p. 203

Au	ρ_0	α_0	β_0
0	11.0	5.3	3.4
1	11.9	4.9	3.4
3	14.3	4.1	3.0
5	16.3	3.6	3.1
10	19.7	3.0	2.8
20	17.0	3.6	3.5
40	20.0	3.3	3.3

Fe-B (298); $\delta_1 = 6.2$

Fe-B-C, Boron steel (219)

B	C	ρ_{25}
0.21	0.18	17.1
0.48	0.22	22.9
0.84	0.21	29.0
0.15	0.47	29.1*
0.41	0.59	29.8*

* Q_{250}.

Fe-Bi; A_{1000} (46)

Bi	ρ
1.0	13.4
2.0	14.5
4.0	15.3
6.0	13.0
10.0	16.6

Fe-C; *v. also* Table 3

For pure Fe, $\delta_1 = 13.3$ (298); $\delta_1 = -1.74$ (146)

Steels

(213)	C	Si	ρ_0	α_0	β_0
Ss*	3	tr.	13.50	3.7	7.4
S*	4	0.1	11.75	6.5	4.3
Sh*	6	tr.	11.25	4.9	8.9
H*	8	0.1	15.42	4.0	5.4

Fe-C.—(*Cont'd*)

Mn, 0.2; Si, 0.1; $t \geq 800$°C (25)

	C	ρ_{800}	D
M*	0.205	42.8	4.86
Sh*	0.493	47.0	4.3
H*	0.841	72.7	2.3
H*	0.82	92.9	2.8
H*	1.05	92.0	2.9
H*	1.16	90.6	2.83
H*	1.38	97.75	3.01

* Ss = very soft; S = soft; Sh = semi-hard; H = hard; M = mild.

Semi-hard steel (161); 0.06C, 0.4Mn

t	ρ
15	20.4
300	54.8
420	70
600	101.9
700	123.5
820	163
960	168
1100	170.6

Hard steel (161)

t	ρ
15	30.6
280	58.6
410	76.4
680	135
730	144
830	177
870	182
940	185.9
1050	188.4

Electrolytic Fe (305)

C	C*	ρ_A	t_A	
0.016	0.004	9.91	905	vac
0.003		10.25	920	vac
0.176		12.58	936	vac
0.206		12.29	936	vac
0.205		12.55	930	vac
0.282		11.82	930	vac
0.284		12.2	930	vac
0.224	0.235	12.0	900	N_2
0.224	0.151	12.4	900	vac
0.315	0.339	12.7	900	N_2
0.315	0.227	13.4	900	vac
0.492	0.485	13.5	900	N_2
0.492	0.387	13.9	900	vac
0.742		13.8	900	N_2
0.742	0.559	14.2	900	vac
0.846	0.85	14.7	900	N_2
0.846	0.791	15.65	900	vac
1.016	0.985	18.7	900	vac
1.016	0.981	18.5	900	vac

* After heat treatment.

Fe-C.—(*Continued*)

Swedish iron + C (127)

t	ρ_t	t	ρ_t	t	ρ_t	t	ρ_t
0% C		0.18% C		0.44% C		0.80% C	
3	15.3	781	102.4	420	56.6	684	110.3
9	20.0	746	97.1	302	44.6	677	106.8
140	23.1	731	93.6	0.64% C		676	102.3
183	26.3	723	91.6	24	16.5	1.02% C	
254	32.0	710	89.8	104	21.5	24	18.3
302	36.4	697	87.1	165	26.2	104	23.3
375	43.6	688	84.4	245	32.7	154	26.9
462	53.1	675	80.9	318	39.4	250	33.6
527	61.6	666	79.9	425	51.2	340	44.2
627	76.4	655	77.8	473	57.4	351	44.9
700	90.2	635	75.9	541	66.3	420	52.4
742	98.7	604	70.9	596	74.2	512	63.0
751	100.7	477	54.8	655	83.8	633	81.1
760	102.2	300	36.2	689	89.3	700	90.4
773	105.3	0.44% C		716	94.2	713	92.2
789	108.6	30	22.9	728	96.4	722	93.4
817	111.3	85	27.2	732	98.5	722	93.7
851	113.8	177	34.0	734	101.4	728	94.8
862	124.5	226	37.1	736	105.2	734	95.8
890	115.8	289	42.4	745	107.6	735	96.4
901	117.0	338	47.2	760	109.7	736	98.4
888	115.1	426	56.9	780	111.4	737	100.4
851	112.9	520	67.5	807	112.3	738	101.8
810	110.3	577	75.4	854	113.8	738	106.4
772	105.8	657	86.6	890	115.5	747	107.3
746	100.0	702	95.8	904	116.3	750	107.6
709	92.1	709	96.8	890	115.8	753	107.9
650	80.7	717	98.0	834	113.8	775	108.3
390	45.3	721	98.8	736	109.7	794	109.1
0.18% C		726	99.4	710	107.2	832	110.6
24	16.5	728	100.3	694	103.6	864	112.1
89	18.3	731	101.0	686	101.8	889	112.8
152	24.3	736	102.8	680	98.5	920	113.9
213	28.9	737	103.9	677	92.8	864	111.9
257	31.8	742	105.9	665	87.5	808	111.9
338	37.8	747	107.3	0.80% C		756	108.1
450	51.4	754	108.1	25	18.7	702	105.9
533	61.0	756	109.2	92	23.2	698	105.7
626	72.2	762	109.7	160	28.3	693	103.2
653	76.6	774	111.3	225	33.4	692	101.4
693	84.3	796	112.3	278	38.2	691	99.6
723	89.5	829	113.5	341	45.2	689	97.6
734	91.1	890	115.8	398	51.6	685	94.8
747	93.7	908	116.2	514	66.0	682	92.9
750	95.0	891	115.8	612	80.4	668	85.3
767	99.4	845	113.6	675	90.2	1.30% C	
777	101.7	813	112.8	683	91.0	81	23.9
799	104.3	762	110.9	721	98.8	117	28.2
809	105.4	753	110.1	732	101.3	260	37.5
823	106.5	746	109.4	738	104.8	365	48.5
832	106.7	728	109.2	741	111.9	477	61.3
835	107.0	721	107.3	754	113.0	538	68.5
843	108.0	710	106.9	764	114.4	606	78.2
866	108.7	707	106.5	797	115.0	634	82.4
890	109.2	673	99.2	841	116.7	660	85.8
918	110.0	670	96.9	880	118.5	700	92.0
891	109.4	662	92.5	913	119.5	710	93.6
862	108.2	651	87.2	870	112.8	719	94.3
839	107.3	651	85.6	818	115.8	722	95.3
818	106.5	628	83.6	748	113.5	727	96.8
797	105.0	518	68.1	704	111.4	728	97.0

Fe-C.—(*Continued*)

Swedish iron +C.—(*Cont'd*)

t	ρ_t
1.30% C	
734	97.5
739	98.6
742	104.4
743	106.7
746	107.5
750	108.0
753	108.7
754	108.5
762	108.8
774	109.8
801	110.8
851	113.1
876	114.3
918	116.8
891	116.5
864	115.5
849	113.0
812	111.8
752	108.8
728	107.8
719	107.2
700	107.2
697	106.4
697	103.7
696	102.4
696	100.4
694	97.8
692	95.1
691	91.5
690	91.1
681	89.4
676	87.9
653	85.2
551	70.7
1.50% C	
23	19.1
86	23.8
160	29.0
247	36.5
338	46.2
432	57.2
562	74.5
606	81.2
653	89.6
698	87.5
708	98.5
712	100.2
719	100.7
723	101.1
728	102.7
735	104.7
736	105.2
737	108.7
738	109.9
739	111.6
741	112.6
746	113.8
753	114.5
816	120.9
877	112.4†

Swedish iron +C.—(*Cont'd*)

t	ρ_t
1.50% C	
907	126.1
888	124.9
841	122.4
832	121.7
826	121.7
791	118.9
783	118.1
767	117.8
703	116.0
990*	112.9
689	110.8
689	109.5
688	106.7
686	103.4
685	101.1
682	97.7
680	95.8
673	93.9
645	88.2
558	74.5
360	49.3

*Probably should be 690.

†Probably should be 122.4.

Soft welding iron; 0.05% C (**161**)

t	ρ_t
15	17.82
290	48.5
460	75.1
750	140.0
800	154
860	166.8
910	170.6
1060	178.2

H-scale of temp. (**169**); *ca.* 1% C

+ 16.2	18.33
−172.7	7.19
−173.9	7.12
−172.2	7.18
−165.2	7.54
−154.8	8.07
−146.9	8.36
−111.0	10.53
−101.9	11.13
− 95.8	11.49
− 92.7	11.69
− 40.8	14.74
− 39.6	14.84
− 36.0	15.08
+ 21.8	18.67
+ 22.1	18.71

Resistivity in magnetic field H (**126**)

t	ρ	t	ρ
0.64%C; H = 80.1		1.02% C; H = 80.1	
240	32.15	704	90.4
281	35.9	715	92.0
342	41.9	723	93.8
427	51.25	737	97.4
487	59.8	760	103.4
561	68.8	772	106.1
659	82.8	779	108.1
672	85.3	784	109.4
679	86.4	801	111.0
686	87.8	819	112.3
711	91.7	822	113.6
735	96.1	828	114.1
748	99.6	838	115.0
762	102.8	848	116.0
770	104.9	859	116.6
789	108.0	872	118.0
810	110.8	872	118.0
826	112.7	858	116.6
846	114.3	831	115.3
873	115.4	821	114.4
867	115.2	815	113.7
851	114.6	802	112.8
821	113.45	788	111.4
801	112.3	776	110.7
784	110.8	761	109.2
763	108.0	750	107.0
750	105.4	744	105.9
742	103.1	731	103.3
714	96.2	720	100.3
698	91.9	712	97.8
687	89.1	706	95.6
675	86.4	701	93.8
662	84.2	694	92.1
652	82.4	687	89.4
622	77.2	680	86.6
560	68.9	667	84.25
488	58.7	653	82.0
427	51.25	637	80.0
343	42.1	553	68.2
280	35.9	442	53.9
230	31.1	369	46.6
		278	37.5
		222	33.5
1.02% C; H = 80.1		179	29.5
13	19.0	154	28.0
116	25.7	133	26.4
213	32.4	71	22.2
251	35.5	1.30%C; H = 80.1	
312	41.2	14	65.1
375	46.9	67	68.5
433	53.0	164	75.3
479	59.0	223	80.3
530	65.2	299	86.8
612	75.9	348	91.2
634	79.2	403	97.1
645	80.6	452	103.0
654	81.9	492	107.4
663	83.3	511	109.5
673	84.6		

Fe-C.—(*Continued*)

Resistivity in magnetic field H.—(*Continued*)

t	ρ	t	ρ	t	ρ	t	ρ
1.30% C; H = 80.1		1.30% C; H = 80.1		0.18% C; H = 187		0.44% C; H = 187	
559	115.9	716	147.0	721	95.9	631	81.6
588	119.8	701	142.0	730	97.8	647	83.7
606	121.4	686	137.4	743	101.3	656	85.0
610	122.6	677	135.0	753	103.8	668	87.0
632	125.6	662	130.7	757	105.1	677	88.5
642	127.0	652	128.9	775	107.3	687	90.0
655	129.1	642	127.5	788	108.9	703	92.7
668	131.0	632	125.9	801	110.6	712	94.1
678	132.6	602	121.9	807	111.4	722	96.2
685	134.7	537	112.5	813	111.7	727	97.4
697	136.5	389	95.5	823	112.6	730	97.9
731	144.3	270	84.4	834	113.4	734	99.4
740	147.0	226	79.8	845	114.4	742	101.4
750	150.1	196	77.6	863	115.4	752	103.4
756	151.6	157	74.6	872	115.7	762	105.1
760	152.5	101	70.8	876	116.0	771	106.5
772	154.0	83	69.2	0.44%C; H = 187		780	108.0
794	157.4	0.18% C; H = 187		15	22.4	789	109.2
810	159.0	15	18.6	69	25.9	796	110.0
824	159.9	124	25.9	126	29.5	806	111.2
837	160.7	177	29.6	193	34.1	814	112.0
864	161.8	230	33.8	238	37.7	826	112.5
876	162.0	281	38.1	290	41.9	828	112.7
888	161.8	331	42.7	323	45.0	835	113.0
858	159.7	341	43.5	349	47.2	840	113.1
838	158.8	395	49.0	372	49.8	845	113.4
825	158.1	473	58.6	391	51.6	862	113.8
811	157.3	526	65.1	425	55.5	871	114.0
797	156.3	596	75.0	466	60.2	882	114.2
771	154.6	650	83.2	513	65.6	890	114.3
758	153.8	660	85.3	600	77.2	899	114.2
741	152.0	691	90.7	617	79.4	907	114.0
725	149.4					917	113.8

Fe-C-*x*

Carbon steels; composition of x, $\frac{1}{100}$%

Key	Cr	Cu	Mn	Ni	S	Si	P
1			2.5		0.4	0.6	1.2
2		3	4		2.4	12	1
3		3	1		2.2	11	1
4		3	7		2.1	13	1
5		3	8		2.1	13	1
6		4	10		2.1	13	1
7		3	7		2.4	11	1
8		3	9		2.0	13	1
9		3	8		2.1	12	1
10		3	10		2.2	12	1
11		3	12		1.9	13	1
12		3	13		1.9	14	1
13		3	12		1.4	15	1.8
14	3	5	13	6	2.2	4	1.2
15	3	6	12	6	1.4	11	1.0
16	4	6	13	5	1.8	13	1.0
17			6		1.5	1.5	3
18			12		4.2	21	1.2
19			12		2.5	6	0.5
20			19		2.5	5	1
21	5		23		1.4	23	1.6

Fe-C-x.—(*Continued*)

Elec. Fe + additions (241)

C + x	0.019 + 1		0.11 + 2	
α_0*	5.51		5.25	
t_Q			900	950
Δ_Q†			0.088	0.410
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	10.949	0.535	12.093	0.452
100	15.466	0.747	16.872	0.607
150	20.990	1.708	20.436	0.634
200	24.529	2.318	23.395	1.480
250	28.190	3.295	27.480	1.835
300	32.827	3.662	31.710	2.256
350	38.196	3.540	37.350	2.113
400	44.300	2.806	42.916	2.184
450	51.010	2.930	49.330	2.112
500	57.844	3.050	55.671	2.609
550	64.800	2.320	62.717	2.608
600	72.853	2.931	69.905	2.820
650	81.274	2.808	78.572	2.608
680	86.522	5.002	83.928	2.116
690	88.110	7.074	85.690	2.468
700	89.820	7.562	87.382	4.018
710	91.890	7.570	89.144	7.046
720	93.968	7.441	90.976	7.684
730	98.850	5.491	93.160	7.820
740	101.53	4.89	95.630	7.390
750	103.73	4.64	98.800	6.200
760	105.800	4.03	101.470	5.430
770	107.270	3.78	103.730	4.930
780	108.120	4.03	105.770	4.87
790	108.850	3.91	107.110	4.79
800	109.831	3.54	108.380	4.52
850	113.492	2.56	112.960	3.46
860			113.810	3.31
870			114.660	3.16
880	115.687	1.71	115.570	2.75
890	116.178	1.706	116.420	2.18
900	116.665	1.710	117.050	1.90
910	117.273	1.347		
920	117.519	1.464	118.400	1.33
930	117.884	1.466		
940	118.249	1.343		
950	118.620	1.215	119.800	0.70
980	119.716	0.975	121.000	0.63
1000	120.447	0.609	121.560	0.56
1020	121.183	0.606	122.400	0.22
1050	122.153	0.247	124.030	
1080	123.008	0.123		
1100	123.620			

C + x	0.17 + 3		0.35 + 4	
α_0*	4.98		4.51	
t_Q	900	950	900	950
Δ_Q†	0.101	0.606	0.551	1.429
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	12.851	0.213	14.636	0.175
100	17.597	0.447	19.465	0.470
150	20.601	1.421	22.783	0.783
200	24.012	1.420	25.986	1.780
250	27.776	1.564	30.045	1.852
300	32.181	1.562	34.460	1.993

* 25 to 100°C.

† $\Delta_Q = \rho_Q' - \rho_Q''$; ρ_Q' (ρ_Q'') = ρ for specimen quenched at t_Q (at 850°).

‡ $\Delta_c = \rho_{tc} - \rho_{th}$; ρ_{th} (ρ_{tc}) = ρ_t for heating (cooling).

Elec. Fe + additions.—(*Continued*)

C + x	0.17 + 3		0.35 + 4	
α_0*	4.98		4.51	
t_Q	900	950	900	950
Δ_Q†	0.101	0.606	0.551	1.429
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
350	37.083	2.273	40.511	1.495
400	43.334	2.122	46.064	2.136
450	49.160	2.555	51.831	2.279
500	55.554	2.556	58.381	2.279
550	62.657	2.130	64.930	2.138
600	70.260	2.200	73.190	0.513
650	78.286	2.554	81.380	0.851
680	83.544	2.626	86.504	0.784
690	85.250	2.696	88.284	1.068
700	86.882	3.128	90.064	2.208
710	88.730	5.751	91.844	7.548
720	90.434	6.466	93.480	10.610
730	92.350	6.965	95.402	10.608
740	94.840	6.750	97.540	10.390
750	98.745	5.045	102.740	7.260
760	101.440	4.480	107.510	4.270
770	103.720	4.120	109.640	3.190
780	105.850	3.910	111.280	2.700
790	107.270	3.480	112.630	2.070
800	108.550	3.120	113.350	1.840
850	112.950	2.700	116.190	0.930
860	114.310	1.840		
870	115.650	0.996		
880	116.510	0.560	117.540	0.780
890	117.000	0.427		
900	117.356	0.494	118.250	0.720
920	118.067	0.353	118.970	0.640
950	119.210	0.280	120.180	0.500
980	120.270	0.140	121.110	0.420
1000	120.830	0.150	121.820	0.140
1020	121.550	0.070	122.530	0.070
1050	122.610		123.600	

C + x	0.45 + 5		0.54 + 6	
α_0*	4.24		4.09	
t_Q	900	950	900	950
Δ_Q†	0.830	1.792	0.239	1.262
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	15.333	0.147	16.506	0.151
100	20.225	0.163	21.421	0.521
150	23.301	0.852	25.240	0.431
200	27.563	0.710	28.110	1.433
250	31.683	0.997	31.910	1.792
300	36.087	1.777	36.283	2.295
350	41.354	1.838	42.450	1.434
400	47.100	1.757	48.330	1.291
450	53.142	1.700	53.934	0.562
500	59.177	2.485	60.592	0.932
550	65.924	1.776	66.686	+2.297
600	73.313	1.847	77.720	−1.569
650	81.696	1.422	82.680	+0.572
680	86.740	1.420	87.626	1.004
690	88.310	1.554	89.562	0.648
700	89.937	1.774	91.212	0.716
710	91.500	9.020	92.860	4.302
720	93.275	13.285	95.082	12.838
730	95.190	13.500	96.802	13.838
740	97.325	13.285	98.452	14.198
750	104.290	8.090	103.110	10.830

Fe-C-x.—(*Continued*)

Elec. Fe + additions.—(*Continued*)

C + x	0.45 + **5**		0.54 + **6**	
α_0*	4.24		4.09	
t_Q	900	950	900	950
Δ_Q†	0.830	1.792	0.239	1.262
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
760	109.540	4.120	110.570	4.090
770	111.460	2.980	112.940	2.290
780	112.960	1.840	114.150	1.440
790	113.820	1.260	114.940	1.080
800	114.230	1.210	115.380	1.070
850	116.360	1.070	117.450	1.010
880	117.430	1.280	118.460	0.930
900	118.140	1.280	119.110	1.000
920	118.850	1.210	119.890	0.860
950	119.920	0.990	121.040	0.740
980	120.980	0.780	122.040	0.500
1000	121.690	0.640	122.760	0.360
1020	122.400	0.500	123.470	0.220
1050	123.46		124.56	
C + x	0.63 + **7**		0.81 + **8**	
α_0*	4.20		3.81	
t_Q	900	950	900	950
Δ_Q†	0.309	1.806	3.982	5.014
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	16.727	−0.169	17.790	0.128
100	21.617	+0.500	22.925	0.051
150	25.296	0.554	26.227	0.939
200	29.029	0.761	29.840	1.228
250	33.175	0.347	33.741	1.734
300	37.807	0.206	38.221	1.879
350	43.474	0.138	43.567	1.300
400	49.420	0.137	49.637	1.155
450	55.640	0.205	55.271	1.445
500	62.273	0.208	61.270	2.310
550	69.050	0.273	68.060	2.457
600	76.511	0.275	75.864	1.300
650	84.322	0.342	83.740	0.940
680	89.300	0.344	88.724	1.010
690	90.890	0.412	90.530	1.157
700	92.614	0.486	92.050	1.300
710	94.136	7.534	93.855	7.875
720	95.794	14.656	95.370	17.990
730	97.525	15.685	97.032	17.488
740	99.460	15.620	99.057	15.823
750	108.160	8.090	107.290	8.240
760	115.570	1.170	114.810	1.070
770	116.940	0.210	115.530	0.860
780	117.360	0.200	115.750	1.080
790	117.770	0.210		
800	118.190	0.140	116.470	1.080
850	120.260	0.140	118.340	1.230
880	121.440	0.070	119.430	1.230
900	122.130	0.090	120.150	1.160
920	122.410	0.340	121.020	1.010
950	123.440	0.280	122.110	0.930
980	124.410	0.210	123.410	0.350
1000	125.100	0.140	124.120	0.220
1020	125.790	0.140	124.850	0.360
1050	126.760		125.930	

*25 to 100°C.

†$\Delta_Q = \rho_Q' - \rho_Q''$; ρ_Q' (ρ_Q'') = ρ for specimen quenched at t_Q (at 850°).

‡$\Delta_c = \rho_{ic} - \rho_{ih}$; ρ_{ih} (ρ_{ic}) = ρ_t for heating (cooling.)

Elec. Fe + additions.—(*Continued*)

C + x	0.89 + **9**		1.00 + **10**	
α_0*	3.68		3.99	
t_Q	900	950	900	950
Δ_Q†	1.596	2.393	1.797	2.877
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	19.309	0.298	19.091	−0.377
100	24.628	0.414	24.537	+0.043
150	28.835	0.000	27.898	0.919
200	32.555	0.429	31.853	0.565
250	36.704	0.573	36.162	0.495
300	41.355	0.788	40.965	0.212
350	47.080	0.714	46.474	0.353
400	52.874	0.572	52.125	0.713
450	58.670	0.859	57.916	0.494
500	65.110	0.714	64.131	0.989
550	71.548	0.715	70.981	0.919
600	78.776	1.000	78.043	0.497
650	86.574	0.858	85.954	0.566
680	90.940	1.500	90.756	0.636
690	92.440	1.502	92.312	0.916
700	94.017	1.429	93.864	0.778
710	95.660	12.160	95.632	3.957
720	97.450	19.240	97.466	14.834
730	99.310	18.030	99.305	17.165
740	101.610	16.160	101.000	16.380
750	106.250	11.950	109.190	8.690
760	117.050	1.580	116.530	1.770
770	117.550	1.436	116.890	1.837
780	117.986	1.424	117.313	1.837
800	118.840	1.290	118.230	1.700
850	120.986	1.224	120.350	1.347
880	122.277	0.573	121.764	1.126
900	123.060	0.720	122.470	1.130
920	123.780	0.714	123.250	0.987
950	124.780	0.720	124.450	0.632
980	125.856	0.714	125.365	0.421
1000	126.500	0.710	126.000	0.285
1020	127.210	0.720	126.774	0.146
1050	128.356		127.830	
C + x	1.22 + **11**		1.43 + **12**	
α_0*	3.81		3.35	
t_Q	900	950	900	950
Δ_Q†	2.615	4.212	2.416	4.046
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
25	21.011	0.489	22.888	−0.129
100	26.356	1.994	28.611	−0.126
150	32.053	1.069	32.077	−0.278
200	36.470	1.850	35.547	+0.070
250	40.600	2.850	39.714	0.276
300	45.444	2.849	44.295	0.695
350	50.574	2.849	49.433	0.972
400	55.701	2.707	55.404	+0.696
450	61.400	2.564	62.170	−0.030
500	67.668	2.065	68.041	+0.556
550	74.078	2.068	74.638	0.208
600	81.560	1.922	81.790	0.136
650	89.750	1.424	89.564	0.208
680	94.310	1.636	94.284	0.836
690	95.878	1.850	95.812	0.832
700	97.300	2.280	97.410	0.832
710	98.890	15.790	98.943	0.479
720	100.435	17.305	100.530	9.860
730	102.214	16.240	102.614	14.859

Fe-C-x.—(*Continued*)

Elec. Fe + additions.—(*Continued*)

C + x	1.22 + **11**		1.43 + **12**	
α_0*	3.81		3.35	
t_Q	900	950	900	950
Δ_Q†	2.615	4.212	2.416	4.046
t	ρ_t	Δ_c‡	ρ_t	Δ_c‡
740	104.138	14.818	104.280	13.750
750	113.968	5.412	109.620	8.893
760	118.170	1.640	117.888	1.045
770	118.454	1.713	118.235	1.115
780	118.880	1.710	118.724	1.106
790	119.380	1.709	119.350	0.900
800	119.876	1.640	119.900	0.700
840	121.730	0.853		
850	122.156	1.284	122.056	0.484
860	122.510	1.430		
870	122.730	1.570		
880	123.154	1.496	123.377	0.273
900	123.869	1.351	124.140	0.345
920	124.580	1.417	124.970	0.210
950	125.579	1.281	126.220	0.070
960			126.500	0.064
970			126.847	0.071
980	126.786	0.858	127.120	0.140
1000	127.570	0.710	127.680	0.140
1020	128.427	0.500	128.235	0.138
1050	129.635		129.070	

C + x	1.54 + **13**		C + x	1.54 + **13**	
α_0*	3.43		α_0*	3.43	
t_Q	900	950	t_Q	900	950
Δ_Q†	4.406	5.319	Δ_Q†	4.406	5.319
t	ρ_t	Δ_c‡	t	ρ_t	Δ_c‡
25	21.550	−0.073	760	119.860	2.366
100	27.120	−0.146	770	120.220	2.434
150	30.664	+0.286	780	120.575	2.505
200	34.318	0.932	800	121.578	2.582
250	38.043	2.149	850	123.946	2.854
300	43.058	1.719	880	125.380	2.861
350	48.649	1.931	900	126.450	2.800
400	54.449	1.647	920	127.670	2.724
450	60.540	1.790	950	129.250	2.215
500	66.700	1.720	960	129.750	2.074
550	73.650	1.720	970	130.173	2.003
600	81.171	1.937	980	130.680	1.860
650	88.982	2.004	990	131.181	1.719
680	93.710	2.364	1000	131.609	1.791
690	95.145	2.791	1010	131.900	1.715
700	96.646	4.014	1020	132.185	1.645
710	98.225	16.407	1030	132.540	1.480
720	99.942	20.350	1040	132.975	1.125
730	101.735	19.129	1050	133.050	1.250
740	103.740	17.624	1080	133.900	0.600
750	107.107	14.687	1100	134.600	

* 25 to 100°C.

† $\Delta_Q = \rho_{Q'} - \rho_{Q''}$; $\rho_{Q'}$ ($\rho_{Q''}$) = ρ for specimen quenched at t_Q (at 850°).

‡ $\Delta_c = \rho_{t_c} - \rho_{th}$; ρ_{th} (ρ_{t_c}) = ρ_t for heating (cooling).

Fe-C-x.—(*Cont'd*)

C (262)	x*	ρ_{20}
0.05	**14**	12.09
0.12	**14**	12.80
0.22	**14**	13.94
0.43	**14**	14.78
0.50	**14**	15.66
0.58	**15**	16.44
0.63	**15**	16.06
0.78	**15**	17.11
0.86	**15**	17.79
0.97	**15**	18.26
1.09	**16**	18.62
1.33	**16**	18.84
1.40	**16**	18.98
1.52	**16**	19.42
1.49	**16**	19.79
1.65	**16**	20.63
1.64	**16**	19.87

* *See* p. 175.

C (93)	x	ρ_{18}	α_0
0.105	**17**	10.11	5.4
0.57	**18**	16.4	3.5
0.99	**19**	16.35	3.9
1.50	**20**	18.15	3.3
Eutectoid (206)			
0.85	**21**	20.25*	

* Air-cooled; furnace-cooled, ρ = 19.3 to 19.6.

Effect of drawing to wire (**13, 14, 68**)

C	ρ_A	ρ_D	Lit.
0.028*	10.5	10.47	(**13, 14**)
0.35†	22.0	21.6	(**68**)
0.79†	21.7	20.9	(**68**)

* Pure commercial iron, 0.028C, 0.07Si, 0.009(S + P); t = 18°, α_D = 6 for 0 to 150°C.

† Initial diameter = 6 mm, drawn to 1.5 mm. For unannealed; ρ_O = 25.2, ρ_D = 20.8 if C = 0.35; and ρ_O = 27.0, ρ_D = 21.0 if C = 0.79.

Fe-Co, Tp_{900} (46)

Co	ρ
0.32	14.4
0.58	15.5
1.035	12.5
2.0	13.5
3.0	14.3*
4.055	15.4
6.02	18.3

Electrolytic Fe; F (300)

0	9.9
34.6†	9.4
A_{900}	
0	9.85
34.6†	9.94
A_{1100}	
34.6†	9.85

* ρ_{Hm} = 14.7; for Tp_{1000}, ρ = 11.7.

† Fe_2Co.

Fe-Co.—(*Continued*)

Co	ρ
(200)	
0	12.0
10	16.3
20	20.0
30	20.0
100	9.7

Fe-Co-x* (124)

Co	ρ
0	16.62
5	21.94
10	24.76
15	25.26
20	23.53
30	16.45
40	13.48
50	11.24
70	9.21
80	13.37
90	16.37
100	8.59

* Impurities in Fe = 0.31Mn, 0.288Cu, 0.11Si, 0.030P, 0.026S, 0.09C; in Co = 1.4Fe, 1.1Ni, 0.14Si, 0.24C.

Fe-Co-Mn-Si-C (12, 13)

t = 18°C; t_A = 1000°C

Co	Mn	Si	C	ρ_A	ρ_O
1.8	1.0	0.64	0.25	23.2	27.3
7.0	0.8	0.80	0.52	30.7	33.6

Fe-Cr; at 18°C, δ_2 = 10, δ_3 = 11.5, δ_5 = 14 (9)

Tp_{900} (46)

Cr	ρ
3.27	26.7
6.00	37.5*
6.68	39.7
8.83	46.8
13.01	46.0
16.57	50.0

* ρ_{Hm} = 52.5; for Tp_{1000}, ρ = 64.4.

Cr	ρ_{20}	α_{20}
(135)		
0	9.96	4.80
9.1	41.1	2.33
13.0	41.2	2.33
16.7	52.1	2.47
20.0	43.7	2.30
(200)		
0	12.0	
10	54.0	
20	60.0	
22	60	
24	57.8	
30	55.9	

Cimet (65)

Cr	ρ_{17}	ρ_{1100}
25	17.3	45
25	43.9	114.2

Fe-Cr-Al-C; *v.* **Fe-Al-Cr-C**

Fe-Cr-Al-Cu (46)

Cr	Al	Cu	ρ_{Hm}
8.7	1	1	35.6

Fe-Cr-C (14)

Cr	C	ρ_A
2.00	0.90	21.93
9.50	1.09	34.63

Chrome steel (219); *cf.* (27)

Cr	C	ρ_Q*	ρ_O
1.20	0.06	18.0	16.3
2.66	0.28	31.0	29.7
4.50	0.21	35.0	33.2
7.84	0.07	53.0	50.9
10.14	0.15	50.8	49.7
13.36	0.17	66.6	60.0
14.52	0.38	69.7	62.9
16.71	0.15	68.1	64.7
22.06	0.21	57.7	56.0
25.31	0.24	60.2	57.5
31.75	0.46	66.3	63.7

* t_Q = 980°C; t = 12 to 17°C.

Cr	C	ρ_Q*	ρ_O
0.62	0.86	43.5	23.1
0.99	0.97	50.2	25.8
2.14	0.89	54.0	27.8
4.57	0.79	56.3	29.4
7.28	0.84	62.2	39.1
9.38	0.75	66.5	56.4
13.94	0.70	72.5	65.4
14.54	0.74	73.1	66.2
18.65	0.90	68.3	60.7
26.54	0.82	68.4	67.1
32.46	0.92	67.5	66.3
36.34	0.83	68.5	65.1
40.03	0.80	73.5	71.5

* t_Q = 980°C; t = 15 to 20°C.

0.6% C; cylinders 20 cm long, 5 mm diam. (179)

Cr	ρ_A*	ρ_Q†
0	20.7	20.7
0.5	22.0	22.4
1	21.9	22.8
2	21.1	22.9
3	25.6	35.5
5	32.3	44.8
10	45.4	51.3
15	46.5	60.2
20	51.6	63.7

* t_A = 900°C. † t_Q = 1100°C.

18°C (12, 13)

Cr	C	ρ_A*	ρ_O
2.0	0.90	24.2	
3.25	0.43	24.9	35.55
9.50	1.09	38.2	43.45

* t_A = 1000°C; t = 18°C.

0°C (118, 176)

Cr	C	ρ_O	ρ_A*	ρ_Q
0.29	0.16	22.34	19.17	19.05
1.18	0.27	33.51	33.05	57.06
5.19	0.77	20.12	22.34	40.62
9.18	0.71	23.15	24.01	28.43
1.12	0.54	19.78	17.15	32.06

Fe-Cr-C.—(*Cont'd*)

Cr	C	ρ_O	ρ_A*	ρ_Q
2.19	0.20	27.04	20.43	29.07
4.17†	0.08	33.47	25.70	29.56

* Straining the annealed wire decreases ρ by about 4 %.

† 13 % Cr, ρ_0 = 52, α_0 = 1, 20 to 100°C (148).

Fe-Cr-Cu-Al; *v.* **Fe-Cr-Al-Cu**

Fe-Cr-Cu-C (12, 13)

Cr	Cu	C	ρ_A*	ρ_O
5.75	1.80	0.85	31.2†	42.7

* t_A = 1000°C. † t not stated; at 18°C, ρ_A = 29.2 (13).

Fe-Cr-Mn-C; *v.* **Fe-Mn-Cr-C-(Si)**

Fe-Cr-Mn-Ni-Mo-C (46)

Cr	Mn	Ni	Mo	C	ρ_{Tp}*	ρ_{Hm}
10	10	10	6	1	78.0	63.8

* t_{Tp} = 1000°C.

Fe-Cr-Mn-Si-(V) (46)

Cr	Mn	Si	V	ρ_{Tp}*	ρ_{Hm}
20	3	1		67.1	65.3
21.4	3	1	1	82.0	76.8

* t_{Tp} = 1000°C.

Fe-Cr-Mn-Si-C; *v.* **Fe-Cr-Si-C-(Mn, P, S)**

Fe-Cr-Mo-(Mn, Si, V, C) (46)

Cr	Mo	Mn	Si	ρ_{Tp}*	ρ_{Hm}
10	5			50.0	47.9
10	10			49.4	48.1
5	4	3	1	54.0	48.6

* t_{Tp} = 1000°C.

Fe-Cr-Mo-W-(Si, V, C); *v.* **Fe-Cr-W-(C, Mo, Si, V)**

Fe-Cr-Ni; *v.* **Fe-Ni-Cr**

Fe-Cr-Ni-C; *v.* **Fe-Ni-Cr-C**

Fe-Cr-Ni-Mn; *v.* **Fe-Ni-Cr-Mn**

Fe-Cr-Ni-Mn-Mo-C; *v.* **Fe-Cr-Mn-Ni-Mo-C**

Fe-Cr-Ni-Si; *v.* **Fe-Ni-Cr-Si**

Fe-Cr-Ni-Si-V (46)

Cr	Ni	Si	V	ρ_{Tp}*	ρ_{Hm}
20	10	1	0.3	75.7	76.0

* t_{Tp} = 1000°C.

Fe-Cr-Si (46)

Cr	Si	ρ_{Tp}*	ρ_{Hm}
4.0	0.84	46.9	41.6
5.0	0.84	39.6	39.6
5.0	1.4	57.0	47.7
6.0	0.4	42.4	35.0
6.0	0.84	49.1	42.4
6.0	1.3	59.5	47.4
8.0	1.0	61.2	53.2
10.0	2.0	59.8	75.0
10.0	3.0	84.0	87.5
10.0	5.0		103.0
13.0	1.8	85.6	75.8
15.0	2.0		92.6
17.0	1.5	76.0	72.8

* t_{Tp} = 1000°C.

Fe-Cr-Si-C-(Mn, P, S)

Steels; t_A = 1000°C, t_Q = 940°C, t_{Tp} = 1100°C

t = 18°C (12, 13)

Cr	Si	C	ρ_A	ρ_O
2.0	1.00	0.76	31.8	36.4
2.0	1.80	0.86	44.1	51.0
3.5	2.25	0.54	50.6	54.8

t = 15°C (165, 166); *v. also* Table 4

Cr	Si	Mn	C	ρ_{Tp}	ρ_O
2.5	0.27	0.23	0.50	40.9	19.5
2.8	0.27	0.21	0.82	66.7	21.5
2.4	0.36	0.21	1.07	72	24

$t \gtrsim$ 800°C (25)

Cr	Si	Mn	C	ρ_{800}	D
2.19	0.27	0.23	0.50	99.0	3.1
2.83	0.27	0.21	0.82	81.2	1.7
3.44	0.36	0.21	1.07	87.7	2.55

t = 0°C; *v. also* Table 4 (128); ($\frac{1}{1000}$%) 42P, 20S

Cr	Si	Mn	C	ρ_A	ρ_Q
620*	220	393	532	19.42	27.08
1195*	134	28	687	18.49	30.35

* ρ_F for 620Cr = 20.16, for 1195Cr = 17.91.

t = 25°C; before (after) decarbonization ($\frac{1}{1000}$%); 1400Cr, 450Si, 380Mn, 7P (50)

S	C	ρ_A	ρ_Q	
11	1050	24.20	49.60	Before
3	350	26.57	27.25	After

Fe-Cr-Si-Ni-C (134); 22.06Cr, 1.67Si, 0.87Ni, 0.18C

t	ρ_t	t	ρ_t	t	ρ_t
20	97.5	500	119.5	800	130.6
300	110.1	600	125.7	900	132.4
400	114.6	700	128.4	1000	134.2

Fe-Cr-Si-(Ti, V, C) (46); Cr10, Si2

Ti	V	C	ρ_{Tp}*	ρ_{Hm}
2			86.0	79.5
	0.3	0.6	77.4	59.2
	1.0	0.3	84.9	83.4

* t_{Tp} = 1000°C.

Fe-Cr-V-(C) (46)

Cr	V	C	ρ_{Tp}*	ρ_{Hm}
5.0	0.3		35.7	35.0
5.0	0.5		34.4	34.4
5.0	1.0		26.8	36.1
10.0	0.3		45.7	49.2
10.0	0.5			51.3
10.0	1.0		74.8	45.9
10.0	0.3	0.65	55.0	49.9

* t_{Tp} = 1000°C.

Fe-Cr-W-(C, Mo, Si, V†) (46)

Cr	W	Mo	Si	C	ρ_{Tp}*	ρ_{Hm}
2	10				28.3	28.0
3	10				30.5	30.0
10	2				51.5	51.4
10	10				57.8	60.7
5	2			0.6	57.8	47.4
5	5			0.6	57.8	56.8
10	2			0.6	55.7	53.6
7	3	2			40.9	43.9
10	2	2			49.7	50.9
10	2	2		0.6		61.6

Fe-Cr-W-(C, Mo, Si, V).—(*Continued*)

Cr	W	Mo	Si	C	ρ_{Tp}*	ρ_{Hm}
7.23	9		3		87.9	89.5
10	2		2			72.8
10	5		3		87.9	92.2
10	2	2	2		83.8†	77.4†
6	18			0.69	48.0†	50.3†
10	2				49.8†	53.3†
10	2			0.6	60.4†	60.0†

* t_{Tp} = 1000°C.
† Alloys so marked contain 0.3 % V.

Steel: t = 18°C; t_A = 1000°C (12, 13)

Cr	W	C	ρ_A	ρ_O
0.75	2.0	0.25	17.9	22.5

Fe-Cu; *v. also* **Cu-Fe**; δ_1 = −0.18 (146); both electrolytic (45, 46)

Cu	ρ	Cu	ρ	Cu	ρ
Tp_{900}		Hm		A_{1000}	
0.089	12.2	0.5	14.0	0.5	12.2
0.202	12.0	1.0	11.4	1.0	11.8
0.422	13.6	1.0	16.4	1.0	13.2
0.804	13.6	2.0	15.6	2.0	11.2
1.006	14.7	3.0	15.5	2.5	9.5
1.51	17.0	3.5	14.7	3.0	12.4
2.005	13.4	4.0	13.6	3.5	8.6
3.99	12.7	5.0	15.7	4.0	12.5
5.07	12.5	90.0	5.09	5.0	12.8
6.16	12.7	90	5.53		
7.05	15.8	98	4.46		
94.34	3.92				

Fe-Cu-(Al, As, Mn, Si) (46)

Cu	Al	As	Si	ρ_A*	ρ_{Hm}
1.0	0.5			14.5	18.8
2.0	0.5				18.5
3.0	1.0			8.0	21.8
5.0	1.0			18.1	20.0
5.0	1.0			17.6	19.9
6.0	1.0			17.6	19.8
3.0		1.0		15.1	22.1
5.0		1.0		19.6	20.5
0.5			0.25	13.1	17.0
0.5			0.5	21.8	22.0
1.0			0.5	18.3	21.7
1.0			1.0	19.2	22.9
2.0			1.0	22.2	24.8
3.0			0.5	8.1	20.2
3.0			1.0	17.8	25.3
5.0			1.0	22.6	25.3
5			2	26.5	
6			1	22.8	
6.67			6.67	15.7	23.4

* t_A = 1000°C.

Steels (12); *cf.* (13); 18°C

Cu	Al	Mn	C	ρ_A*	ρ_O	ρ_D†	α_0†
1.59		0.36	0.68	14.9	19.8	13.92	4.18
2.50		0.32	0.59	14.4	19.0	13.55	4.57
2.87		0.14	0.17	17.4	21.5	16.15	3.66
3.75	1.0	0.16	0.04	21.0	24.9	20.77	2.80

* t_A = 1000°C. † Wire; annealed.

Fe-Cu-Ni-Mn-C; *v.* **Fe-Ni-Cu-C-(Mn)**

Fe-Cu-W-Cr-C; *v.* **Fe-W-Cu-Cr-C**

Fe-Mn; δ_1 = 6.27 (146); at 18°C, δ_2 = 16, δ_3 = 18, δ_5 = 24.5 (9).
S = 0 to 0.028; C = 0 to 0.003 (305)

Mn	ρ
A_{950}, vac (305)	
0.036	10.19
0.047	10.4
0.074	10.7
0.16	10.81*
0.16	11.04*
0.32	11.55*
0.29	12.24
0.54	13.42
0.59	15.04
A_{1000} (46)	
1.0	18.4
2.0	24.8
3.0	28.4

Fe-Mn.—(*Cont'd*)

Mn	ρ
A_{1000} (46)	
3.5	30.6
6.0	40.0
8.0	53.0
10.0	55.8
Tp_{900} (46)	
0.505	16.1
4.514	30.1
10.419	55.3
Hm (46)	
3.5	30.2
6.0	40.8
8.0	49.1
10.0	54.8
Drawn and annealed (135)	
9.1	46.8
13.04	58
16.67	61

* A_{918}.

Mn (76)	ρ_0	Δ_{100}
12	67.148	1.27

Fe-Mn-C (12, 13, 14)
For Hadfield's Mn-steel, *v.* **Fe-Mn-Si-C-(P, S)**

Mn	C	ρ_A*	ρ	ρ_O
0.50	0.20	14.46	13.09	14.96
1.00	0.24	23.57	21.34	24.94
2.25	0.41	29.18		31.86
3.50	0.08†	29.67		31.29
4.00	0.36	28.69	25.98	33.74
4.75	0.36	29.38		38.23
5.15	0.32	37.41		46.50
5.40	0.15	33.74	30.52	46.51
13.00	0.26	61.50	55.6	63.70
15.20	0.15	64.94	58.9	67.00

Mn	C	ρ_A	Mn	C	ρ_A
1.00	0.75	26.88	11.50	1.66	61.50
3.81	0.78	44.12	13.00	1.23	63.60
7.00	1.20	58.74	15.25	1.50	66.18
10.10	0.16‡	63.72	18.50	1.54	69.0

* 18°C. † 0.13 % Si. ‡ 0.63 % Si.

1/100 %					19–25°C
Mn	C	P	S	Si	ρ
Iron (52)					
0	8	13	0.8	2.4	12.54
tr.	2.8	0.4	0.5	7	10.35
1.8	16	4.9	1.1	1.5	10.80
2.7	17	7.4	2.2	7.7	11.92
3.6	3.0	6.5	1.6	14	11.00
6.4	15	3.6	2	13	13.82
6.8	15	13	2	15	13.80
7.4	16	12	2.7	10	13.10
10	5.8	1.4	tr.	1.2	10.82
18.0	5.0	1.3	1.1	2	11.40

Fe-Mn-C.—(*Continued*)

1/100%					19–25°C
Mn	C	P	S	Si	ρ
Steel (52)					
14.7	161	1.5	1.8	9.2	18.95
19	5	5.4	5.9	3	11.01
21	19	2.5	4	3.4	12.69
22	21.5	5.1	11.3		12.53
22.2	140	1	2.0	8.2	21.29
25	10	4	2	5	13.90
28	28	2.7	3.4	4	13.18
37	19	9	5	1	13.27
37	25	4	3	1.8	13.31
38	16	8	4	0.9	12.87
40	7	8	17	1.3	13.18
41	14	11	5	0.9	13.80
41	25	10	4	3	14.49
41	27	2.4	1	0.1	13.25
42	28	2.2	4	0.8	13.07
45	15	1.1	3.3	tr.	12.73
45	31	10	4	2.6	14.57
46	14.4	9	8	tr.	14.73
48	16	9.1	4	1	13.86
48	18.8	9	8	tr.	14.62
48	23	2.4	1	2.3	13.67
49	23	2.4	tr.	0.4	13.30
49	33	6.8	5	2	15.32
55	10	8	5	2.4	13.83
56	22	2.4	34	tr.	14.15
57	19.2	2.4	34	tr.	14.03
57	24	2.9	1	0.3	13.64
65	28	8.3	6	5	16.21
66	16	7.4	3.0	1.4	16.09
68	22	7.7	7	5	16.09
72	41	3.9	4.1	11	18.17
73	37	9	4	6	17.10
77	43	10	4	6.6	19.80
80	23	1.6	3.3	1.6	17.10
80	36	10	4	4.7	19.80
83	26	5.3	1	0.4	16.25
87	36	8	9	4	17.27
89	23	5.8	1	0.5	16.32
95	20	10	8	5	19.87
95	30	6.3	1	1	16.96
99	29	8.4	1	1	16.95
108	22	10	5	6	19.81
109	17	9	5	0.4	20.90
127	33	9	5	5	22.72
158	74	4.3	3.6	20	19.69

Fe-Mn-C-(P, S, Si); *cf.* **Fe-Mn-P-(C, Si, S), Fe-Mn-Si-C-(P, S), Fe-Si-Mn-C-(S, P)**

Steel: 0.114Mn, 0.06Si, 0.05P, 0.04S, 0.206C. Manganese: 1.90Al, 0.46Si, 0.24Fe, 0.07C (178)

Mn	ρ	Mn	ρ	Mn	ρ
0.11	14.8	1.1	20.7	5.0	44.8
0.31	17.5	1.6	22.4	7.9	54.0
0.6	19.0	2.0	26.3	8.8	52.9
0.8	19.95	3.0	30.9	9.8	54.9

Si = 0.1 to 1.4, P = 0.01 to 0.03, S $\lesssim$ 0.01; 0.1 to 0.2% C (27)

Mn	ρ_{18}	Mn	ρ_{18}	Mn	ρ_{18}
0.432	15.5	6.139	59.4	12.92	75.8
2.150	25.4	10.512	73.1	14.4	72.5

Fe-Mn-C-(P, S, Si).—(*Continued*)

Si = 0.05 to 1.5, P = 0.01 to 0.024, S = 0.01 to 0.025; 0.8 to 0.9%C (27)

Mn	ρ_{18}	Mn	ρ_{18}	Mn	ρ_{18}
0.461	27.9	3.084	40.3	10.08	70.2
1.031	31.0	5.112	51.8	12.096	71.2
1.972	38.4	7.2	63.5		

Si = 0.058 to 0.128, P = 0.023 to 0.049, S = 0.007 to 0.032 (27)

Mn	C	ρ_{18}	Mn	C	ρ_{18}
0.05	0.15	11.6*	0.40	0.57	17.5
0.40	0.09	13.4	0.40	0.92	18.6
0.40	0.29	15.7			

* Puddled iron.

Mn	Si	C	ρ_{17} (12)
0	0.08	0.14	13.4
0.10	0.10	0.78	16.1
0.14	0.12	1.23	19.1
0.18	0.20	0.84	17.2
0.25	0.06	0.83	16.7
0.32	0.17	0.85	17.9
0.32	0.17	1.09	17.6

0°C (176)

Mn	Si	C	ρ_A	ρ_Q
0.14	tr.	0.39	11.34	12.66
0.30	0.056	0.49	13.26	14.47
0.42	0.086	0.43	13.71	15.43
0.64	0.031	0.37	16.18	19.11
0.74	0.044	0.48	16.93	21.80
1.36	0.167	0.47	20.44	28.80

0°C; t_Q = 850 to 1050°C; 0.017P, 0.030S (176); *cf.* (174)

Mn	Si	C	ρ_A	ρ_Q
		0.035	10.58	11.4
0.42		0.11	11.39	11.88
0.44		0.22	12.06	13.16
0.42	0.085	0.43	13.51	15.44
0.50	0.051	0.66	14.50	18.55
0.34	0.092	0.72	15.84	20.38
0.31	0.145	0.79	16.07	23.93
0.24	0.124	0.92	16.13	24.30
0.30	0.089	1.02	16.19	29.02
0.34	0.110	1.08	17.55	30.07
0.27	0.040	1.17	18.43	32.80
0.40	0.104	1.30	18.57	38.88
0.23	0.113	1.43	18.07	38.50
0.30	0.080	1.54	17.99	37.95

Mn-steel (274)

$10^{-10}\delta_{tr} \equiv (\rho_{tr} - \rho) \div \rho$; $10^{-6}\delta H \equiv (\rho H - \rho) \div \rho$

ρ_{tr} = value of ρ when longitudinal traction is 1 g cm^{-2}; ρH = value of ρ when longitudinal magnetizing field is 1 cgsm unit

ρ_{Dd}	ρ_A	δ_{tr}	δH
74.84	72.91	+11.30	+0.03

Fe-Mn-Cr-C-(Si) (12, 13); 18°C

Mn	Cr	Si	C	ρ_A*	ρ_O
2.60	9.22		1.36	63.7	69.4
3.00	5.00		1.15	47.8	68.3
3.09	8.92		1.30	36.6	50.6
17.50	3.50		0.88	68.8	79.3
4.25	2.00	1.50	1.32	52.1	68.6

Fe-Mn-Cr-Ni-Mo-C; *v.* **Fe-Cr-Mn-Ni-Mo-C**

Fe-Mn-Cu-C (12, 13); 18°C

Mn	Cu	C	ρ_A*	ρ_O
2.0	1.75	0.25	25.2	29.5
8.0	2.75	0.64	51.8	71.4

* t_A = 1000°C.

Fe-Mn-Mo-Ni-Si (46)

Mn	Mo	Ni	Si	ρ_{T_D}*	ρ_{Hm}
12	6	2	0.8	67.1	68.5

* t_{T_D} = 1000°C.

Fe-Mn-Ni; *v.* Fe-Ni-Mn

Fe-Mn-Ni-Cr-Mo-C; *v.* Fe-Cr-Mn-Ni-Mo-C

Fe-Mn-P-(C, Si, S) wire (287); *cf.* **Fe-Mn-C-(P, S, Si), Fe-Mn-Si-C-(P, S), Fe-Si-Mn-C-(S, P), Fe-C-(*x*)**

Mn	P	Si	S	C	ρ
0.00	0.019	0.07	tr.	0.02	9.30
0.00	0.022	0.01	0.00	0.02	9.69
tr.	0.044	0.00	tr.	0.02	9.44
0.10	0.023	0.01	0.01	0.14	9.55
0.12	0.109	0.08	0.01	0.13	12.10
0.15	0.116	0.10	0.01	0.09	11.51
0.09	0.118	0.16	0.05	0.11	10.81
0.13	0.128	0.08	0.01	0.04	11.74
0.11	0.157	0.07	0.01	0.06	11.80
0.32	0.043	0.00	0.00	0.03	10.19
0.29	0.048	0.01	0.06	0.01	10.69
0.28	0.058	0.00	0.06	0.03	10.96
0.27	0.063	0.00	0.05	0.03	10.45
0.33	0.063	0.00	0.05	0.02	10.49
0.40	0.115	0.00	0.06	0.03	12.38
0.47	0.085	0.00	0.03	0.08	14.56
0.49	0.141	0.00	0.08	0.01	10.09
0.59	0.101	0.00	0.04	0.05	13.34
0.69	0.096	0.00	0.02	0.08	14.32
1.22	0.101	0.01	0.01	0.16	16.70
1.17	0.127	0.01	0.02	0.11	18.23

Fe-Mn-Si-C-(P, S); *cf.* **Fe-Mn-C-(P, S, Si), Fe-Mn-P-(C, Si, S), Fe-Si-Mn-C-(S, P), Fe-C-*x***

Square bars, 20 cm long, 1 cm side; t_A = 600°C (165, 166)

Mn	Si	C	ρ_A	ρ_{T_D}
0	0	0	9.5*	
0	0	6.68	45†	
0.13	0.05	0.06	10.0	
0.15	0.08	0.20	12.5	
0.24	0.05	0.49	14.0	
0.24	0.13	0.84	16.0	
0.21	0.11	1.21	18.0	
0.14	0.09	1.40	18.4	
0.13	0.08	1.61	19.0	
0.24	0.1	0.9	17.8	
0.83	0.2	1.2	24.5	
0.95	0.1	0.9	22.0	
1.8	0.9	1.2	40.0	
13	0.3	1	80.0‡	
Fagersta steels (21); 0.026% P; t = 20°C				
0.321	0.009	0.16	12.59	13.6
0.431	0.019	0.23	13.74	15.4
0.412	0.040	0.33	14.67	17.2
0.422	0.078	0.38	15.11	18.3
0.409	0.308	0.62	20.82	30.6
0.449	0.303	0.95	21.11	38.6

* Ferrite, pure iron. † Cementite, Fe_3C. ‡ When magnetized, ρ_A = 66.

Fe-Mn-Si-C-(P, S).—*(Continued)*

t_A = 1000°C, t = 18°C (12); *cf.* (13)

Mn	Si	C	ρ_A	ρ_O
tr.	0.07	0.028	10.2*	10.5*
0.036	0.14	0.03	10.9†	11.1†
0.18	0.02	0.05	11.3‡	11.5‡
	0.08	0.14	13.0	13.4
0.10	0.10	0.78	14.6	16.1
0.25	0.06	0.83	15.2	16.7
0.18	0.20	0.84	16.1	17.2
0.32	0.17	0.85	16.4	17.9
0.32	0.17	1.09	16.2	17.6
0.14	0.12	1.23	17.6	19.1
0.58	0.49	0.58	20.7	23.1
0.58	0.49	1.00	23.3	25.2
0.62	0.46	1.25	23.6	26.6
10.08	0.63	0.16	61.1	65.5
2.00	4.25	0.40	68.4	73.8

* P = 0.004, S = 0.005. † P = 0.065, S = 0.016. ‡ P = 0.013, S = 0.011.

$t \geq$ 900°C (208)

Mn	Si	C	ρ_A	α_{900}
0.43	0.24	0.08		0.33
0.35	0.02	0.11		0.33
0.57	0.33	0.22		0.43
0.47	0.13	0.37		0.38
0.25	(?)	1.05		0.40

$t \geq$ 800°C (25)

Mn	Si	C	ρ_{800}	D_{800}
1.83	0.882	1.183	110.9	2.26
2.20	0.984	1.941	111.3	3.3

Gysinge steels, t = 15–18°C, t_{T_D} = 800°C (20, 21)

Mn	Si	P	S	C	ρ_A	ρ_{T_D}
0.13	0.03	0.009	0.005	0.08	10.5	10.9
0.29	0.12	0.013	0.02	1.50	17.9	50.6
0.29	0.08	0.013	0.03	1.70	17.7	
0.35	0.65	0.015	0.02	0.45	23.9	29.0
0.44	0.86	0.014	0.02	0.55	27.6	34.4
0.41	0.28	0.014	0.015	0.90	20.2	36.9
0.44	0.30	0.014	0.01	1.20	20.9	42.1
0.54	0.26	0.014	0.015	1.35	21.6	44.4

t = 0°C; quenched in oil (50, 128)

Mn	Si	P	S	C	ρ_A	ρ_Q	ρ_F
0.016		0.005	0.018	1.184	15.88	36.47	
4.73	0.608	0.078	0.023	0.674	39.28	55.56	53.68
7.97	0.502	0.128	tr.	4.510	105.20*		
8.74	0.094	0.072	0.024	1.298	63.16	70.66	69.93
12.36	0.204	0.070	0.038	1.005			65.54
11.57	0.25	0.055	0.026	0.133	51.93	57.77†	
11.57	0.25	0.055	0.023	1.150	53.85	68.57	

* Spiegeleisen.

† After decarbonization of the following specimen.

Hadfield's 12% Mn steel; α_{15} = 1.27 (63)

t	ρ_t	t	ρ_t	t	ρ_t	t	ρ_t
−197.1	55.414	−81.9	61.236	+1.0	67.222	89.9	75.294
−106.1	60.042	0	67.148	16.15	68.520		

Fe-Mn-Si-C-(P, S).—(*Continued*)

Effect of drawing to wire (84); *cf.* (85)

ρ_D is after 7 drawings; t = 16 to 18°C, BB = Bessemer Base steel; OH = Open Hearth steel; specimens a and b; HR = hot rolled; HRA = hot rolled and annealed; D = drawn; DA = drawn and annealed.

1/100%	Mn	Si	P	S	C
BB	48	0.6	8.0	5.6	7
OH_a	47	26.2	6.8	3.6	55
OH_b	38	11.3	1.6	1.9	78

Steel	BB	OH_a	OH_b
t_A	400	910	1000
ρ_A	12.2	11.85	11.96
ρ_{HR}	14.38	21.70	18.80
ρ_{HRA}	14.32	21.40	18.60
ρ_D	14.72	19.40	20.47
ρ_{DA}	14.60	19.50	20.46

Fe-Mn-Si-Cr-C-(P, S); *v.* **Fe-C-*x***

Fe-Mn-Si-Cu-C-(P, S) (252); *cf.* **Fe-C-*x***

1.0 to 5.1P, 1.4 to 4.4S; $t_A = t_Q$ = 900°C; 1/100%

Mn	Si	Cu	C	ρ_A	ρ_Q	ρ_F
39	31	10	14	19.1	19.3	19.1
34	10	10	18	17.5	17.7	17.5
65	23	13	31	20.0	23.6	21.5
67	34	9	44	21.4	24.1	23.2
30	18	9	56	18.9	19.7	18.9
27	6	9	64	17.7	18.2	17.8
35	10	7	75	19.3	20.1	19.4
30	10	8	80	19.2	20.2	19.1
35	13	8	94	19.9	23.0	19.9
36	8	5	102	20.0	24.1	19.6
40	8	6	130	21.8	22.3	20.9
36	5	5	150	21.8	25.0	21.8

Fe-Mn-Si-Cu-Ni-Cr-C-(P, S); *v.* **Fe-C-*x***

Fe-Mn-W-C; 18°C (12, 13); *cf.* **Fe-W-Mn-C**

Mn	W	C	ρ_A*	ρ_O
2.25	3.25	0.40	27.7	37.1
3.25	10.00	1.52	31.3	45.4
10.20	2.11	1.08	65.8	71.3
11.10	2.85	1.34	68.4	74.5

* t_A = 1000°C.

Fe-Mo (46)

Mo	ρ_{Tp}	ρ_{Hm}	Mo	ρ_{Tp}	ρ_{Hm}
5.12	27.8*		12.0	32.6†	36.6
9.84	29.9†		13.69	35.1†	

* t_{Tp} = 900°C. † t_{Tp} = 1000°C.

Fe-Mo-C; t = 17 to 19°C; t_H = 950°C (219)

Mo	C	ρ_N	ρ_H
0.45	0.19	16.2	17.8
1.00	0.16	16.5	17.1
2.20	0.14	18.2	20.0
4.50	0.29	30.2	31.8
0.50	0.74	18.1	37.6
1.21	0.81	23.4	39.5
1.98	0.81	25.6	40.7

Fe-Mo-C.—(*Continued*)

0°C (176)

Mo	C	ρ_A	ρ_O
0.95	0.283	15.17	21.68
0.95	0.283	15.36*	17.91†

* After straining, ρ_A = 15.27.
† ρ_Q = 19.79, t_Q = 900°C.

Fe-Mo-Cr-Si-Mn-C-(P, S) (50)

5.07Mo, 3.98Cr, 0.90Si, 0.33Mn, 0.013P; 25°C; t_Q = 940°C

S	C	ρ_A	ρ_Q
0.042	1.67	40.03	65.83
0.008*	0.220*	54.73	54.08

* After decarbonization.

Fe-Mo-Cr-V-C (46)

Mo	Cr	V	C	ρ_{Tp}*	ρ_{Hm}
10	2	0.3	0.5	38.9	37.0

* t_{Tp} = 1000°C.

Fe-Mo-Mn-(Si, C, etc.)

Mo	Mn	ρ_{Tp}*	ρ_{Hm}	Lit.
2	1	20.6	22.3	(46)

* t_{Tp} = 1000°C.

0.025S, 0.016P, 0.020As, 0.0045N; 16 to 20°C; *v. also* Table 4 (268, 269)

Mo	Mn	Si	C	ρ_A	ρ_N
1.030	0.218	0.047	0.195*	13.48	14.51
1.054	0.230	0.087	0.445	14.77	16.55
1.018	0.270	0.122	0.869	18.55	20.47
1.096	0.250	0.124	1.215	19.54	20.32
2.176	0.216	0.064	0.246	13.55	16.73
2.181	0.270	0.075	0.442	14.97	16.42
2.186	0.263	0.078	0.883	16.13	18.80
2.109	0.238	0.071	1.210	18.47	21.72
2.540	0.205	0.122	1.360	20.13	21.79
4.110	0.242	0.036	0.190	14.95	16.40
4.009	0.292	0.038	0.487	14.89	16.39
4.002	0.230	0.051	0.865	15.53	18.42
4.019	0.230	0.039	1.060	16.92	19.37
8.012	0.216	0.049	0.135†	23.70	25.76
8.167	0.274	0.056	0.361	15.32	17.20
8.109	0.252	0.080	0.445	14.38	16.79
7.847	0.230	0.041	0.775	15.38	17.87
7.920	0.234	0.075	1.125	16.13	18.86

* 0.005 % Al.
† 0.004 % Al.

Fe-Mo-Ni-Si; *v.* **Fe-Ni-Mo-(Si, C)**

Fe-Mo-V-(C) (46)

Mo	V	C	ρ_{Tp}*	ρ_{Hm}
4	0.6		22.6	17.8
5	1.0		25.0	22.9
8	0.5		25.4	25.1
10	0.3		27.2	27.3
10	0.5		30.3	30.7
10	1.0		29.4	30.1
10	1.0		32.1	30.1
8	0.3	0.6	27.8	22.6
10	0.3	0.4	26.6	17.1
10	1.0	0.4	19.9	24.2

* t_{Tp} = 1000°C.

Fe-Ni (146)

For nickel steels and named alloys containing mainly Fe and Ni, *see* **Fe-Ni-C.**

$\delta_1 = 1.46$ (9); at 18°C, $\delta_2 = 7$, $\delta_3 = 9$, $\delta_5 = 13$; Tp_{900} (45, 46, 193)

Ni	ρ
0	12.1
0.27	13.1
0.56	15.4
1.07	16.9
1.93	16.4
7.05	26.9
8.17	26.7
10.20	28.6
11.29	29.4
12.07	30.3
13.11*	34.8
19.21	36.2
22.11	38.7
25.20	63.2
26.40	65.5
28.42	82.0
35.09	81.1
47.08	44.7
75.06	22.1
100.00	12.4

* +0.89 % C.

Ni (76)	ρ_0	α
95	29.45	2.01

Ni (137)	ρ_{20}	Δ_{100}
4.0	20.9	2.0
7.0	25.2	2.3
13.0	33.0	1.8
14.0	33.9	1.6
18.0	35.9	0.84
21.0	38.8	1.8
22.11	40.0	1.8
26.40	35.9	1.6
35.09	92.0	1.1
40.0	74.1	2.2
47.08	47.5	3.6
90.0	15.5	3.4

Electrolytic;* t_A = 902 to 1064°C, vac (301)

Ni	ρ_A
0.50†	11.5
1.01	12.7
1.48†	13.8
1.96†	14.9
2.44†	16.1
2.84	17.1
3.85†	19.4
4.62	20.3
5.67	22.0
7.33	24.8
8.00†	25.2
9.61	27.1
14.92	29.8
15	30‡
30	82§
34.81	80.4

Fe-Ni.—(*Cont'd*)

Ni	ρ_A
(200)	
0	12
17	38.2
29	79.5
34	86.3
81	23.9
93	18.1
98	11.9
100	11.8
(238)‖	
0	12
5	29
10	31
15	39
20	39
25	40
30	87
35	94
40	81
45	48
50	43
55	41
60	30
65	27
70	27
75	19
80	18
85	20
90	22
95	19
100	9

* Impurities in Fe = 0.005Al, tr. (Cu, Mn, P, Si), 0.003S, 0.014C; in Ni = 0.250Fe, tr. Mn, 0.001P, 0.006S, 0.040Si, 0.030C. Amount of Ni in alloy determined by analysis excepting those marked "†."

† Amount of Ni added to the Fe.

‡ Unchanged by precooling to − 70°C.

§ After precooling to −70°C, ρ_{20} = 38; to −185°, ρ_{20} = 32.

‖ Impurities in Fe = 0.03Cu, 0.06-Mn, 0.01P, 0.01S, 0.01Si, 0.08C.

(105, 193)

Ni	$1000\Delta_t$
22.0*	$784 - 0.13t$
26.2	$844 + 0.01t$
28.7	$700 - 0.20t$
30.8	$897 - 0.43t$
35.0	$1561 - 1.69t$
35.7	$1161 - 1.68t$

* +3 % Cr.

0 to 370°C (214)

Ni	ρ_0	α	β
25	76.2	1.15	−0.59

$10^{-10}\delta_{tr} \equiv (\rho_{tr} - \rho) \div \rho$; $10^{-6}\delta_H \equiv (\rho_H - \rho) \div \rho$ (274); ρ_{tr} = value of ρ when longitudinal traction is 1 g cm^{-2}; ρ_H = value of ρ when longitudinal magnetizing force is 1 cgsm unit.

Fe-Ni.—(*Cont'd*)

Ni	ρ_{Dd}	ρ_A	δ_{tr}	δ_H
0	12.09	10.74	+13.23	+23.35
22	47.98	75.08	+ 7.53	+ 3.06
25	60.94	78.72	+ 6.64	+ 1.48
30	55.08	87.93	− 1.34	+ 4.56
100	17.57	17.36	−40.8	+80.7

Fe-Ni-C (246)

t	ρ
25.2 % Ni; 0.35 % C	
16.0	77.85
56	81.43
99	83.60
137	85.24
171	86.71
201	88.41
233	89.65
268	90.89
305	92.50
332	93.67
345	94.25
368	95.19
389	95.95
411	96.57
438	97.70
469	98.89
492	99.53
537	100.8
549	101.4
561	101.7
577	102.1
608	103.3
643	103.9
675	105.1
715	105.6
732	106.5
762	107.0
792	107.7
818	109.0
843	109.5
885	110.9
903	111.4
914	111.6
930	111.4
947	111.7
977	112.3
995	**112.8**
970	112.4
945	112.0
926	111.5
906	111.2
895	110.8
875	110.4
841	109.5
804	108.9
777	108.0
745	107.1
610	103.5
580	102.5
550	101.8
510	100.6
305	93.89
270	92.93
241	91.86

Fe-Ni-C.—(*Cont'd*)

t	ρ
25.2 % Ni; 0.35 % C	
177	89.10
156	88.75
35	84.90
30.6 % Ni;* 0.34 % C	
167	87.28
262	91.23
291	92.37
318	93.68
358	94.82
385	95.76
413	96.70
439	97.64
478	98.96
509	99.91
553	101.2
574	101.8
600	102.5
625	103.3
653	104.1
681	104.6
701	105.2
747	106.1
780	107.1
807	107.6
834	108.4
860	109.1
885	109.7
903	110.1
917	**110.5**
868	109.3
825	108.4
794	107.6
767	106.9
746	106.3
710	105.0
683	104.4
653	103.7
614	102.5
582	101.4
544	100.5
515	99.53
480	98.21
453	97.27
423	96.32
392	95.00
360	93.87
320	92.37
270	90.67
60	81.81
35.25 % Ni; 0.33 % C	
16	81.87
90	88.09
124	89.79
169	92.33
207	94.31
243	95.59
275	96.86
310	97.85
340	98.98
370	99.97
423	101.1

Fe-Ni-C.—(*Cont'd*)

t	ρ
35 25% Ni; 0.33% C	
463	101.2
467	100.7
467	98.13†
516	99.26
516	98.84‡
571	**99.69**
527	98.70
500	97.71
462	96.86
454	96.86
441	96.86
422	96.58
369	95.16

* For Ni-steel, 30 % Ni, $\rho = 85$; $\alpha = 0.8$ if $20° < t < 100°$ (148).
† Constant after 75 min.
‡ Constant after 20 min.

Ni-steel (219); *cf.* (27)
t = 20 to 21°C; t_Q = 975°C

Ni	C	ρ_N	ρ_Q
2.23	0.07	16.6	20.0
5.23	0.12	22.2	22.4
7.13	0.12	24.9	25.8
10.10	0.13	28.7	28.6
12.07	0.12	30.1	30.1
15.17	0.11	32.8	32.5
20.40	0.18	33.5	33.3
25.85	0.16	40.3	37.8
30.00	0.12	82.4	82.4
1.97	0.21	17.7	19.3
4.90	0.20	23.7	24.9
7.59	0.23	25.4	27.8
9.79	0.21	32.0	32.0
12.29	0.22	34.9	35.0
20.01	0.22	44.7	43.1
25.06	0.23	72.0	73.2
27.87	0.19	82.6	82.6
2.20	0.80	21.9	36.6
4.90	0.78	31.4	46.2
7.09	0.81	37.0	50.2
9.79	1.05	40.2	51.7
12.27	0.76	49.0	55.2
15.04	0.80	71.0	70.6
20.01	0.80	74.8	70.8
25.06	0.79	80.4	79.1
29.96	0.81	85.4	85.4

Ni(220)	C	ρ_s*	ρ_f*
7.0	0.6	42.9	30.6
7.0	0.75	44.5	31.0
7.1	0.8	44.9	33.6
9.7	0.35	36.1	30.7
9.9	0.8	55.9	40.0
11.7	0.5	55.3	45.7
12.2	0.4	40.4	36.0
15.0	0.3	69.7	49.0

* For ρ_f, annealed from 1000°C, cooling in 4 to 5 hr; for ρ_s, annealed from 1300°C, cooling in *ca.* 3 days.

Fe-Ni-C.—(*Cont'd*)
0°C; t_Q = 900°C (176)

Ni	C	ρ_A	ρ_O	ρ_Q
1.07	0.072	13.17	14.02	12.97
3.37	0.163	18.59	20.69	18.48
5.35	0.199	22.35	23.18	25.62
5.35	0.199	22.28*	22.96	

* After straining = 22.16.

Effect of chilling (123); t_A = 900°C; $\rho_c = \rho_A$ after cooling in liquid air

Ni	ρ_A	ρ_c
0	19.85	19.85
4.6	27.6	27.5
9.2	35.6	36.2
13.8	37.75	39.05
18.5	45.05	41.3
21.2	49.7	44.85
23.6	54.9	42.9
25.8*	69.0	38.75
27.7	93.4	41.65
29.1	98.0	42.55
30.5	92.6	51.3
32.8	99.0	99.0
36.9	80.0	
55.4	39.05	
73.8	27.4	
83.0	21.8	
92.3	20.0	

* For 25 % Ni, *ca.* 74 % Fe: Magnetizable form, $\rho = 52$, $\alpha = 1.32$ at 20°, $\alpha = 4.0$ just below 600°, $\alpha < 1.32$ above 600°; nonmagnetizable form, $\rho = 72$ (129).

Hadfield's 4.35% Ni-steel (63)

t	ρ_t
−197.1	19.468
−106.1	23.750
− 81.9	24.897
0	29.452
+ 0.95	29.515
16.15	30.402
91.15	35.185
$\alpha_{15} = 2.01$	

Named alloys:

Cx	Climax
FN	Ferronickel
Ir	Invar
	Kruppin, *v.* Vn
Pe	Platinite
Vn	Vestalin

Ni	ρ	α
Cx,* FN (65, 66, 175); 20°C		
25	80–83	0.8–0.98
Vn (160)		
28	83–85	0.7–1.3
Ir; 0°C		
36	75	2.0
Pe; 0°C		
46–48	45	3
FeNi, 51.4% Ni (135)		
Cx	87	0.67
FN	28	2.1

* May contain 1 % Mn.

Fe-Ni-Cr (135); *v. also* **Ni-Cr-(Fe, Mn)** and **Ni-Cr-Fe**

Ni	ρ_{20}	α_{20}
9.1% Cr		
0	41.13	2.23
22.7	74.39	0.84
45.45	95.94	0.56
68.2	93.45	0.40
90.9	67.80	0.37
13.04% Cr		
0	41.16	2.33
21.76	76.88	1.05
43.48	90.40	0.59
65.2	101.30	0.21
86.96	84.10	0.20
16.7% Cr		
0	52.07	2.47
20.8	79.35	0.91
41.6	103.67	0.34
50	105.38	0.23
62.5	108.04	0.21
83.3	96.90	0.12

Fe-Ni-Cr.—(*Cont'd*)

Ni	ρ_{20}	α_{20}
20% Cr		
0	43.68	2.30
20	82.36	0.90
40	97.01	0.38
60	106.46	0.24
80	99.79	0.14

t_{Tp} = 1000°C (46)

Ni	Cr	ρ_{Tp}	ρ_{Hm}
8	10	67.3	68.4
10	2	45.8	44.9
10	5	59.4	55.7
10	7	67.3	64.4
10	10	33.2	66.9
12	10	62.5	99.6

No. 193 (Driver-Harris) (65, 175); *v. also* **Fe-Ni-Cr-Mn-(P, S, Si, C)**

Ni	Cr	ρ_{20}	α
30	1.5	87	0.014
35.3	31.2	91.4	0.8
Comet (65)			
30	5	95.6	0.34

Fe-Ni-Cr-C, Steel (12, 13); 18°C

Ni	Cr	C	ρ_A*	ρ_O
2.00	2.00	0.90	25.3	25.6
2.50	1.75	0.31	27.7	35.1
2.50	4.50	0.41	35.1	43.0
2.75	0.75	0.25	23.9	24.9
3.25	1.75	0.86	28.5	40.9
12.24	2.01	0.64	52.1	55.2

* t_A = 1000°C.

Ni	Cr	C	ρ	α	Lit.
10	10	1	69.7*		(46)
Steel; *v. also* **Ni-Fe-Cr**					
7	18		70	1	(148)
62	12		100	0.2	

* Tp_{1000}; ρ_{Hm} = 73.8.

Fe-Ni-Cr-Mn (200)

Ni	Cr	Mn	ρ
2	25	3	86.5
15	15	6	78.6
16	23	2	85.7
18	15	3	84.2
22	4	3	75.1
29	4	2	83.0
35	10	6	99.0
39	16	3	111.0
49	10	6	111.0
56	19	6	110.0
60	10	6	91.0
66	19	5	105.0

Alloy No. 4 (134); for No. 3, *v.* **Ni-Cr-Fe**
Ni, 27.62; Cr, 21.10; Mn, 0.85

t	ρ	t	ρ
20	103.45	700	127.0
300	115.9	800	129.0
400	119.4	900	131.0
500	122.3	1000	132.85
600	125.0		

Fe-Ni-Cr-Mn-(P, S, Si, C)

Ni, 1.50; Cr, 0.57; Mn, 0.486; Si, 0.162; P, 0.012; t = 25°C, t_Q = 940°C; before (after) decarbonization (50)

S	C	ρ_A	ρ_Q	
0.026	0.354	22.33	26.63	Before
0.014	0.017	21.82	21.92	After

Alloy No. 193 (Driver-Harris); *v. also* **Fe-Ni-Cr**; Ni, 30; Cr, 2; Mn, 1; C, 0.22 (134)

t	ρ (65)	ρ (134)	t	ρ (65)	ρ (134)
20	91.4	95.5	500	114.4	136.10
100	97.3	104.35	600	119.4	140.50
200	102.4	114.45	700	121.25	143.6
300	105.9	123.75	800	125.5	146.9
400	110.7	130.35	900	131.4	151.4

Fe-Ni-Cr-Mn-Mo-C; *v.* **Fe-Cr-Mn-Ni-Mo-C**

Fe-Ni-Cr-Si (46)

Ni	Cr	Si	ρ_{Td}*	ρ_{Hm}
10	10	1	70.9	74.2
10	10	2	76.2	78.8
20	10	2	91.8	93.0

* t_{Td} = 1000°C.

Fe-Ni-Cu-C-(Mn); 18°C (12, 13)

Ni	Cu	Mn	C	ρ_A*	ρ_O
5.75	2.75		0.18	38.2	40.0
2.9	2.9	1.5	0.17	24.9	32.7
14.44	2.25	5.90	0.81	80.0	

* t_A = 1000°C.

Fe-Ni-Mn; 20°C (135)

Ni	ρ
9.1% Mn	
0	46.8
24.7	88.0
45.45	94.7
13.04% Mn	
0	58.0
21.76	88.6
43.48	98.3
65.2	88.3
86.96	41.6
16.7% Mn	
0	61.0
20.8	88.6
41.6	117
62.5	105
83.3	51.2

Ni	Mn	ρ(200)
20	20	94.5
36	9	103.0
36	11	103.0
44	6	87.0
45	4	93.5
59	7	85.5
65	2	54.1

Fe-Ni-Mn-Al-C; 18°C (12, 13)

Ni	Mn	Al	C	ρ_A*	ρ_O
14.1	5.3	2.3	0.43	47.8	88.7

* t_A = 1000°C.

Fe-Ni-Mn-C, Annealed (14)

Ni	Mn	C	ρ
0	tr.	0.03	9.46
0.58	0.18	0.26	16.22
1.92	0.72	0.14	18.58
3.82	0.65	0.19	21.63
19.64	0.93	0.19	35.4
31.40	0.82	0.70	77.9
14.55	5.04	0.80	76.1
25.00	5.04	0.60	80.7

Ni (46)	Mn	C	ρ_{Td}	ρ_{Hm}
5	2	0.6	44.0	35.6
10	1	0.5		32.4

Fe-Ni-Mn-C.—(*Continued*)

Steel; 18°C (12, 13)

Ni	Mn	C	ρ_A*	ρ_D†	α_D‡
1.00	1.00	0.50	28.7	28.63§	1.50
4.00	3.57	0.57	47.5		
19.00	5.04	0.60	82.0	90.62	1.04
25.00	5.04	0.60	89.2	97.52	1.04
30.00	1.50	0.60	88.2	89.17‖	0.85§
31.40	0.82	0.70	86.0	86.6	0.90
2.57	8.00	1.21	70.2		
14.55	5.04	0.80	83.0	83.11	1.09
9.00	10.25	1.40	74.7		

* t_A = 1000°C.
† Wire.
‡ Wire; t = 0 to 150°C.
§ At 18°C.
‖ Rolled; for wire, α = 0.77.

Steel (54); F and A_{1000}

Ni	Mn	C	ρ_{17}
0	0.95	0.47	20.3
1.2	0.79	0.48	22.6
2.15	0.83	0.44	24.8
4.25	0.82	0.40	29.1
4.95	1.03	0.42	39.3
6.42	0.92	0.52	42.8
7.95	0.79	0.43	43.9
12.22	0.85	0.41	50.5
15.98	0.83	0 45	63.3
19.91	0.96	0.41	75.4

Fe-Ni-Mn-Cr-Mo-C; *v.* **Fe-Cr-Mn-Ni-Mo-C**

Fe-Ni-Mn-Cu-C; *v.* **Fe-Ni-Cu-C-(Mn)**

Fe-Ni-Mn-Mo-C (46)

Ni	Mn	Mo	C	ρ_{Td}*	ρ_{Hm}
10	2	2	0.5	63.5	64.2

* ρ_{Td} = 1000°C.

Fe-Ni-Mn-Si-C; 18°C (12, 13)

Ni	Mn	Si	C	ρ_A*	ρ_O
0.00	0.18		0.22	17.0	18.3
0.00	1.00		0.75	26.9	30.2
1.00	1.00		0.50	28.7	30.7
31.40	0.82		0.70	86.0	
1.92	0.72	0.21	0.14	20.44	21.51
3.82	0.65	0.20	0.19	24.57	24.94
11.39	0.93	0.22	0.18	35.82	38.23
19.64	0.93	0.27	0.19	39.01	43.01
24.51	1.00	0.30	0.16	45.12	55.50
0.58	0.18	0.44	0.26	17.9	18.9
0.58	0.18	0.33	0.26	18.31	19.12
12.70	0.61	0.39	0.81	44.1	46.5
12.10	0.61	0.56	0.98	45.3	47.7
30.00	1.50		0.60	88.2	

* t_Q = 1000°C.

$t \simeq$ 800°C (25)

Ni	Mn	Si	C	ρ_{800}	D_{800}
3.03	0.34	0.19	0.70	150.1	3.05
3.62	0.34	0.18	0.57	152.7	4.5
3.73	0.32	0.28	1.21	155.6	4.7

Fe-Ni-Mn-Si-C.—(*Continued*)
Steel [50]; $t = 25°C$; $t_Q = 940°C$

Ni	1/1000%; before decarbonization						
	Mn	Si	P	S	C	ρ_A	ρ_Q
2.80	677	231	38	30	422	26.76	32.63
3.43	660	226	27	34	365	26.80	31.25
5.00	493	267	10	30	182	28.63	30.33
6.00	580	450	30	60	2130	25.43	29.60

Ni	1/1000%; after decarbonization						
	Mn	Si	P	S	C	ρ_A	ρ_Q
2.80	677	231	38	20	36	25.40	26.68
3.43	660	226	27	28	20	25.67	26.33
5.00	493	267	10	17	15	26.78	27.58
6.00	580	450	30	40	180	24.19	24.77

Fe-Ni-Mo-(Si, C) [46]

Ni	Mo	Si	C	ρ_{Tp}*	ρ_{Hm}
10	5			47.5	44.6
20	10			76.8	75.8
10	10		0.5	50.5	55.6
10	10		1	49.7	52.7
20	10		1	78.7	79.6
3.3	7.7	2		52.4	53.6

* $t_{Tp} = 1000°C$.

Fe-Ni-Si [301]; 0.2% Si; t_A = 900 to 1000°C

Ni	ρ_A	Ni	ρ_A	Ni	ρ_A
0.50	12.7	2.90	19.1	9.52	29.6
1.00	14.3	3.85	20.7	15.0	31.0
1.48	15.1	4.76	21.4	30.0	82.0
1.96	16.5	5.67	25.8	34.5	81.3
2.44	18.0	7.00	25.7		

Fe-Ni-Si-C [46]

Ni	Si	C	ρ_{Tp}	ρ_{Hm}
10	2	1.0	70.3	54.2

Steel; 18°C [12, 13]

Ni	Si	C	ρ_A*
1.00	2.00	0.79	50.5
3.25	2.00	0.38	44.0
3.50	3.25	0.22	57.4
12.10	0.56	0.97	45.0†
12.70	0.39	0.81	43.0†

* $t_A = 1000°C$; $t_{Tp} = 1000°C$.
† Contains 0.61 % Mn.

Fe-Ni-Si-Mn; *cf.* **Fe-Ni-Si**; A_{900} [301]; 0.2% Si, 0.1% Mn

Ni	ρ	Ni	ρ
8.0	26.2	50.0	45
10.0	28.9		

Fe-Ni-Ti; A_{900}; vac [301]

Ni	Ti	ρ
9.9	0.20	27.5
15.0	0.20	30.8
50.0	1.0	47.5

Fe-Ni-V [46]

Ni	V	ρ_{Tp}*	ρ_{Hm}
5.0	0.3	24.6	22.3
5.0	0.6	25.0	24.5
10.0	0.3	29.4	30.1
10.0	0.6	32.2	31.2

Fe-Ni-W [46]

Ni	W	ρ_{Tp}*	ρ_{Hm}
15	5	44.9	45.8

* $t_{Tp} = 1000°C$.

Fe-P
Mn, 0.40–0.57; Si, 0.17–0.25; S, 0.05–0.08; C, 0.11–0.155
$t_A = t_Q = 900°C$ [4]

P	ρ_O*	ρ_A	ρ_Q
0.012	17.0	17.2	16.6
0.100	17.6	17.2	18.0
0.144	18.2	18.1	18.9
0.209	19.6	19.1	20.2
0.245	20.3	19.8	21.6
0.266	20.7	20.8	22.1
0.421	22.2	21.9	24.6
0.560	24.2	23.5	25.0
0.725	24.8	24.2	25.7
0.872	27.6	27.2	28.8
1.153	30.7		32.7
1.242	30.9	30.4	32.2

* $\delta_1 = 10.69$ [146]; *v. also* beginning of Fe.

Fe-Pb [46] 0.061% Pb, $\rho_{Tp} = 13.9$, $t_{Tp} = 900°C$

Fe-S [146]; $\delta_1 = 1.80$; *v. also* beginning of Fe

Fe-Sb [46]; 1.0% Sb, $\rho_A = 20.2$, $t_A = 1000°C$

Fe-Se; *v.* beginning of Fe

Fe-Si; $\delta_1 = 20.26$ [146]; at 18°C, $\delta_2 = 26$, $\delta_3 = 34$, $\delta_5 = 49$ [9]

Si	ρ
A_{900} [299, 300]*	
0.001	9.85
0.01	9.89
0.068	10.75
0.148	11.8
0.472	16.2
0.822	21.3
1.74	31.2
3.4	48.5
4.44	57.7
4.92	66.5
A_{1100} [299, 300]*	
0.001	9.84
0.001	9.85
0.01	9.90
0.040	10.50
0.064	10.67
0.068	10.78
0.091	10.96
0.148	11.80
0.205	12.50
0.242	13.40
0.309	14.40
0.400	15.30
0.472	16.57
0.563	17.50
0.673	19.10
0.698	19.60
0.822	21.25
1.71	33.25
1.74	31.00
A_{1100} [299, 300]*	
2.73	42.00
3.40	48.50
3.55	48.50
4.39	56.10
4.44	57.40
4.92	66.20
Tp_{900} [45, 46]†	
0.0	12.1
0.233	14.7
0.603	18.7
1.033	24.3
1.897	34.4
2.826	44.6
3.334	48.6
4.655	62.2
100.0	59.5
A_{1000} [45, 46]†	
0.5	19.8
1.0	15.9
2.5	44.2
5.0	36.9
6.2	74.9
Hm [45, 46]†	
0.5	19.5
1.0	18.6
2.5	45.7
4.0	54.8
4.0	48.6
5.0	40.3
6.2	77.2

* Electrolytic Fe; Si contained 8.50 % Fe, 0.016 % C.
† Elec. Fe; commercial Si.

Fe-Si.—(*Continued*)

Si	ρ
A (209)	
0.24	15.62
0.37	17.21
0.67	21.00
0.95	24.80
1.25	28.90
1.73	40.00
2.35	39.10
2.98	46.50
5.26	64.50
Q (209)	
0.24	16.66
0.37	18.88
0.67	22.20
0.95	29.83
1.25	30.40
1.73	40.80
2.35	41.50
2.98	47.60
5.26	66.00

Fe + 14 to 15% Si, Duriron (69)

ρ_0	ρ_{100}	Δ_{100}
63.3	94.4	4.92

Fe-Si-Al-C (12, 13)

Steel; t = 18°C, t_A = 1000°C

Si	Al	C	ρ_A	ρ_O
2.25	0.5	0.67	43.0	48.6

Fe-Si-C (165, 166)

Si	C	ρ_A*	Si	C	ρ_A*
0.1	0.2	12.5	1.3	0.8	33.5
2.6	0.2	38.5	0.1	1.0	17.8
0.1	0.8	15.8	0.6	1.0	25.5
0.7	0.8	26.5	1.1	1.0	32.0

* t_A = 600°C.

Steel; t = 18°C (12, 13)

Si	C	ρ_A	ρ_O
2.5	0.20	42.1	47.1
5.5	0.26	65.2	68.8

Fe-Si-Mn-C-(S, P) (209); *cf.* **Fe-Mn-C-(P, S, Si), Fe-Mn-P-(C, Si, S), Fe-Mn-Si-C-(P, S), Fe-C-x**

Si	Mn	S	P	C	ρ_A	ρ_Q	ρ_O
0.24	0.41	0.064	0.033	0.12	15.62	16.66	16.98
0.37	0.3	0.049	0.041	0.1	17.21	18.88	18.95
0.67	0.23	0.044	0.044	0.11	21.0	22.2	22.2
0.95	0.36	0.043	0.040	0.11	24.8	29.83	26.2
1.25	0.5	0.042	0.043	0.15	28.9	30.4	30.6
1.73	0.56	0.04	0.045	0.15	40.0	40.8	42.0
2.35	0.29	0.058	0.04	0.12	39.1	41.5	42.5
2.98	0.40	0.045	0.043	0.13	46.5	47.6	49.4
5.26	0.6	0.04	0.031	0.13	64.5	66.0	66

Si	Mn	S	P	C	ρ_A	ρ_Q	ρ_O	ρ_F
Steel (50, 128); t = 25°C; t_Q = 940°C								
0.314	0.275	0.032	0.697	0.045	25.00	26.57		
0.314	0.275	0.046	0.697	1.02	30.12			
0.502	7.970	tr.	0.128	4.510*	105.20†			
0.764	0.386	0.467	0.458	2.036‡	56.61†			
1.476	0.610	0.105	0.435	2.581§	62.86†			
2.044	0.173	0.042	0.151	3.455‖	114.00†			
3.438	0.694	0.024	0.133	0.685	61.85†	61.95¶		61.63*
3.649	0.122	0.017	0.03	0.076	53.60	54.05		
3.649	0.122	0.025	0.03	0.094	54.10	55.22		

Si	Mn	S	P	C	α_{25}	β_{25}	Lit.
1.20	0.29	0.048	0.156	2.30	1.37**	3.05**	(199)
1.20	0.29	0.048	0.156	2.30	0.74‡	1.3‡	

* Spiegeleisen. † t = 0°C (128). ‡ White cast iron; graphitic C = 0. § Mottled cast iron; graphitic C = 1.477 %. ‖ Gray cast iron; graphitic C = 2.064 %. ¶ t = 0°C; oil-hardened (128). ** Malleable cast iron.

Fe-Si-Mn-Cr-C-(P, S); *v.* **Fe-C-x**

Fe-Si-Ni-C; *v.* **Fe-Ni-Si-C**

Fe-Si-Sn; *v.* **Fe-Sn-(P, Si)**

Fe-Sn; Tp_{900} (46)

Sn	ρ	Sn	ρ	Sn	ρ
0.228	13.0	0.717	21.1	3.5	25.0*
0.342	13.3	1.568	22.4	5.0	47.4†
0.686	15.4	2.059	29.8		

* A_{1000}; ρ_{Hm} = 24.1. † A_{1000}.

Fe-Sn-(P, Si) (46)

Sn	P	Si	ρ_A*	ρ_{Hm}
1.0		1.0	19.6	28.1
3.0	0.23		25.6	25.6

* t_A = 1000°C.

Fe-Ta-C, Steel; t = 25°C (219)

Ta	C	ρ_N	ρ_H
0.09	0.12	14.1	14.4
0.15	0.17	14.6	14.8
0.6	0.18	14.8	15.1
1.05	0.16	14.8	15.2

Fe-Ti-C, Steel; t = 18°C; t_H = 950°C (219)

Ti	C	ρ_N	ρ_H
0.42	0.11	13.1	13.6
0.88	0.11	13.8	14.3
1.40	0.14	15.1	15.5
2.57	0.14	16.1	17.0
0.32	0.76	19.8	32.9
0.64	0.70	21.0	32.3
0.72	0.62	21.4	31.0
2.57	0.61	22.2	31.5
4.63	0.63	25.1	34.3
8.71	0.65	28.7	37.9

Fe-V-C, Steel; t = 16 to 23°C; t_H = 1000°C (219)

V	C	ρ_O	ρ_H
0.60	0.13	14.0	15.7
0.75	0.14	15.1	19.9
1.04	0.11	16.2	21.7
1.54	0.13	18.8	21.9
2.98	0.19	30.1	31.8
5.37	0.38	31.7	31.6
7.39	0.13	38.6	38.4

V	C	ρ_N	ρ_H
0.25	0.82	21.4	38.2
0.60	0.72	21.7	37.7
0.80	0.89	22.4	42.6
1.15	0.67	19.3	31.5
2.89	0.95	22.5	31.8
4.99	1.08	20.9	27.6
7.85	0.74	37.5	37.5
10.25	0.86	107.2	107.0

Fe-V-Si (46)

V	Si	ρ_A*	ρ_{Hm}
10	2	75.5	78.9

* t_A = 1000°C.

Fe-W; at 18°C, $\delta_2 = 4$, $\delta_3 = 5$, $\delta_5 = 6$ (9)

W	ρ	W	ρ
Tp_{900} (46)		A_{1000} (46)	
0.406	13.4	9.0	16.5
0.93	13.6	12.0	17.8
2.33	15.1	16.0	19.3
3.35	16.1	18.0	18.7
5.98	16.2	Hm (46)	
9.85	17.1	2.0	19.8
13.64	20.2	4.0	19.5
23.87	18.5	6.0	24.2
A_{1000} (46)		8.0	19.9
2.0	17.6	9.0	23.0
4.0	15.4	12.0	20.7
6.0	16.1	16.0	24.2
8.0	18.2	18.0	23.4

Fe-W-C; t_{T_D} = 1000°C (46)

W	C	ρ_{T_D}	ρ_{Hm}
5.0	0.5	24.5	18.5

Steel; t = 15 to 20°C; t_H = 1000°C (219)

W	C	ρ_N	ρ_H
0.41	0.12	12.8	13.8
0.93	0.11	13.5	14.3
1.75	0.11	15.8	17.1
4.96	0.13	19.5	21.1
6.90	0.13	23.3	23.4
11.89	0.17	20.9	24.5
14.37	0.20	22.6	24.6
20.71	0.22	23.1	25.3
24.35	0.22	25.3	25.2
27.05	0.28	20.7	25.8
0.40	0.86	22.4	39.1
0.95	0.66	20.9	39.6
2.75	0.79	24.3	40.9
4.68	0.33	28.1	41.2
9.99	0.81	26.9	39.5
14.75	0.71	26.5	32.3
19.25	0.74	25.3	31.0

t = 0°C (128); 0.036Mn, 0.043Si, 0.047P; oil-hardened

W	C	ρ_A	ρ_H	ρ_F
4.649	1.357	22.50	22.74	22.49

t = 18°C (27, 28)

W	C	ρ_A	ρ_{T_D}	ρ_O
0.3	0.35	18.4	18.2	17.4
7.0	0.40	42.7	44.3	44.3
10.0	0.50	23.5	26.7	38.2
17.0	0.50	47.8	51.0	51.9
22.0	0.80	62.5	67.5	60.3

t_A.....	900°	900°	1100°	Lit.
C.....	0.3	0.6	0.6	(125)
W	ρ_A	ρ_A	ρ_A	
0	16.5	19.4		
0.5	18.3	21.4		
1.0	19.4	21.4	23.53	
2	20.4	21.8		
3		21.6	28.32	
5	21.1			
6	21.0	21.8	33.11	

Fe-W-C.—(*Continued*)

t_A.....	900°	900°	1100°	Lit.
C.....	0.3	0.6	0.6	(125)
W	ρ_A	ρ_A	ρ_A	
10		23.0		
15	25.6	24.8		
20	29.8	28.1	44.66	
25	37.0	32.8	47.62	

Fe-W-Cr-(Si, C); *v.* **Fe-Cr-W-(C, Mo, Si, V)**

Fe-W-Cu-Cr-C, Steel; t = 18°C; t_A = 1000°C (12, 13)

W	Cu	Cr	C	ρ_A	ρ_O
2.0	2.0	1.75	0.48	31.3*	49.0

* ρ_D = 31.6, α_D = 2.04 for 0 to 150°C.

Fe-W-Mn-C (14); *cf.* **Fe-Mn-W-C**

W	Mn	C	ρ_A
1.00	0.11	0.16	13.65
3.50	0.28	0.28	16.22
15.50	0.28	0.76	24.3
3.25	2.25	0.40	25.16
10.00	3.25	1.50	27.84

Steel; t = 18°C; t_A = 1000°C (12, 13)

W	Mn	C	ρ_A	ρ_O
1.0	0.11	0.16	15.1	15.8
4.5	0.28	0.28	18.0	21.5
7.5	0.20	0.38	19.2	24.6
15.5	0.28	0.76	26.6	35.7

Fe-W-Mn-Cr-Si-C-(P, S) (50)

5.04W, 0.32Mn, 0.24Cr, 0.12Si, 0.018P; t = 25°C, t_Q = 940°C; before (after) decarbonization

S	C	ρ_A	ρ_Q	
0.016	0.083	19.52	29.90	Before
0.006	0.026	24.30	24.07	After

Fe-W-Mn-Si-C-(P, S)

Steel; oil-hardened; no S; t = 0°C (128)

W	Mn	Si	P	C	ρ_H
4.649	0.036	0.043	0.047	1.357	22.74*
3.444	0.625	0.021	0.028	0.511	36.04
2.353	0.312	0.151	0.089	0.855	44.27†

* ρ_A = 22.50. † Very hard.

$t_A = t_N$ = 950°C; t_H = 740 to 810°C (267)

W	Mn	Si	S	P	C	ρ_A	ρ_N	ρ_H
3.25	0.065	0.044	0.055	0.010	0.144	17.31	16.63	19.24
3.24	0.071	0.050	0.050	0.010	0.218	17.50	17.63	19.33
2.92	0.170	0.027	0.014	0.018	0.27		17.63	20.20
3.11	0.075	0.060	0.050	0.010	0.48	18.87	19.12	23.87
3.18	0.140	0.033	0.035	0.012	0.53	18.40	18.46	25.64
3.17	0.080	0.078	0.054	0.010	0.57	18.56	19.98	26.68
3.08	0.093	0.039	0.040	0.012	0.89	17.64	18.76	36.6
3.09	0.055	0.040	0.042	0.012	1.07	16.97	18.43	38.70

t = 15°C; t_{T_D} = 1100°C (25, 165, 166); *v. also* Table 4

W	Mn	Si	C	ρ_{T_D}	ρ_O	$\rho_{t'}$	D_{800}
5.	0.3	0.02	0.6	37.8	21	29.4*	
2.9	0.4	0.2	0.55	32.4	18	79.8†	1.5
2.7	0.44	0.3	0.76	37.0	18.5	84.6†	3.2
2.7	0.38	0.32	1.11	44	20	81.0†	1.83

* t' = 780°C. † t' = 800°C.

Fe-W-(Mo, Cr, V, C) (46)

W	Mo	Cr	V	C	ρ_{T_D}*	ρ_{Hm}
10	10	2	0.3	0.4	38.3	45.8
16	5	2	0.3	0.5	38.8	44.5
4.0			0.4		20.0	18.1
7.0			0.3		22.2	20.3
4.0			0.4	0.5	38.9	23.2
4.0			0.4	0.6	35.0	23.0
4.0			0.4	0.8	43.1	24.1
7.0			0.3	0.6	33.3	24.1

*t_{T_D} = 1000°C.

Hg-Ag

Ag (47)	ρ_{20}	α
0	95.75	0.86
0.0015	95.52	0.91
0.003	94.93	0.87
0.005	94.74	0.84
0.008	94.02	0.84
0.010	93.39	0.84
0.014	91.13	0.92
0.020	87.73	0.92
0.060	71.63	0.94

Ag (187)	ρ_t	t
0.01	93.85	13.1
0.025	93.7	13.2
0.05	93.6	13.4
0.1	93.25	13.0
0.1995	92.75	13.3
0.4975	91.5	13.0
0.99	88.6	13.0

Ag (282)	ρ_{18}	α
0.249	95.5	1.18
0.498	95.5	1.05
0.990	94.9	0.81

Hg-Bi; *v. also* Bi-Hg; for Ag, ρ_0 = 1.54 (298)

Bi	ρ_t	t
0.05	93.7	13.05
0.1	93.6	13.15
0.1995	93.26	13.05
0.4975	92.6	13.45
0.99	92.12	13.25
For Hg, ρ_0 = 94.07, ρ_{20} = 95.76 (159)		
0.061	95.5	20
0.15	95.2	20
0.276	94.8	20
0.448	94.8	26
0.608	94.3	25
0.749	93.95	24.2
0.946	93.55	25.4
1.071	93.3	25.0
1.225	93.0	24.7

Bi	a	b
0.276*	1.0095	31
0.749*	1.0222	48
1.393*	1.0356	68
1.688*	1.0403	80
1.885*	1.0436	84
2.495*	1.0510	112
2.97*	1.0558	115
Sat.†	1.0100	1120

* Unsaturated, $t \lesssim 80°C$.
† Saturated; $15° < t < 40°$.

Hg-Bi.—(*Cont'd*)

Bi (282)	ρ_{18}	α
0.1	95.9*	
0.249	95.3	0.89
0.498	94.4	0.88
0.990	93.25	0.89
0.238		1.106†
0.498		1.150†
0.943		1.203†

* t = 18.6°C, from (184).
† From (18).

Hg-Bi-Pb (71)
20% Bi, 20% Pb

ρ_t	t
92.3	0
95.0	97.5
97.16	143
99.17	181.5
99.86	191.5
00.2	196.5
100.9	214

Hg-Ca (23)

Ca	ρ_{50}	α	β
0.12	97.02	0.834	1.442
$50° \lesssim t \lesssim 300°$			

Hg-Cd (159)

Cd	ρ_t	t
0.016	95.3	17.0
0.032	95.25	18.0
0.065	94.9	16.1
0.098	94.7	16.6
0.145	94.4	16.8
0.19	94.0	16.9
0.28	93.4	16.7
0.375	92.8	17.7
0.47	92.1	17.0
0.55	91.5	17.1
0.64	90.9	15.9
0.735	90.2	16.0
0.83	89.7	16.7
0.925	89.15	16.5
1.03	88.5	16.8
1.065	88.3	16.9
1.21	87.4	17.0
1.295	87.25	20.1
1.395	86.75	21.3
1.58	85.7	21.3
1.77	84.6	20.2
1.955	83.6	20.1
2.09	82.9	20.0
2.27	82.1	19.9
2.43	81.15	19.4

Hg-Cd.—(*Cont'd*)

Cd	ρ_t	t
2.61	80.4	19.6
2.72	79.9	19.7
2.88	79.2	19.7
2.99	78.7	19.6
3.12	78.1	19.4
3.21	77.7	19.4
3.39	76.9	19.4
3.57	76.2	19.7
3.76	75.5	19.8
4.03	74.4	19.8
4.31	73.3	19.4
4.58	72.4	19.3
4.85	71.4	19.6
4.85	71.3	19.6
4.98	70.5	19.3

Cd	a	b
0.375	1.0292	11
0.735	1.0564	25
1.21	1.0911	36
4.98	1.3455	138

Cd (47)	ρ_{20}	α_{20}	β_{20}
0.20	94.36	0.85	1.0
0.43	93.05	0.90	1.0
0.69	91.55	0.79	2.0
0.94	90.20	0.85	1.4
1.50	86.49	0.83	

Cd	ρ_t	α	β
t = 18°C (282)			
0.249	94.8	1.25	
0.498	92.2	0.75	
0.990	89.3	0.86	
t = ? (18)			
0.444		1.096	
0.885		1.096	
1.754		1.103	
t = 50°C (23)			
0.51	94.6	0.922*	1.099*
1.47	87.7	0.815*	1.425*

* α_{50}, β_{50}; $50° \lesssim t \lesssim 300°$.

Cd (284)	R	t
2.55	1.085	263.7
9.41	0.778	264.1
23.41	0.561	264.2
33.25	0.490	263.6
50.90	0.425	264.1
71.58	0.399	267.2

Hg-K (122); *v. also* Table 3

K	ρ_{20}
0	95.76*
0.01137	95.96
0.03496	96.29
0.07956	97.45
0.10945	98.26
0.1274	98.65
0.1726	99.72
0.2334	100.9

* Assumed as basis.

Hg-Li (122)

Li	ρ_{20}
0	95.76*
0.001131	95.72
0.003459	95.59
0.01069	95.19
0.01684	94.79
0.02474	94.39
0.02867	94.14

* Assumed as basis.

Li	ρ_{50}	α_{50}	β_{50}
$50° \lesssim t \lesssim 300°$ (23)			
0.003	98.82	0.943	1.194
0.02	98.32	0.910	1.140
0.04	97.50	0.816	1.393

Hg-Na (122); *v. also* Table 3

Na	ρ_{20}
0	95.76*
0.01070	95.83
0.03339	95.96
0.04430	96.03
0.09990	96.25
0.1387	96.38
0.1944	96.51
0.2468	96.58
0.2824	96.61
0.3104	96.54
0.4338	96.38
0.5893	96.34

* Assumed as basis.

For Hg, ρ_{17} = 95.59 (280)

Na	ρ_{107}	α_{107}*
19.65	124.0	0.54
21.1	123.5	0.40
25.9	119.8	0.13
28.8	115.9	0.32
32.1	110.6	0.16
40.5	93.65	1.30
50.5	74.1	2.38
62.8	55.8	
70.2	40.4	2.26
100	21.74†	12.76

* If $107° < t < 133°$.
† This value unusually great.

Na (232)	δ_f	t_f*
0	76.70	−38.8
Trace	74.50	−40.5
0.658	63.80	−47.93
0.846	59.60	−48.64
1.174	57.70	−48.43
1.560	43.15	−47.85
2.100	42.55	−47.52
2.670	37.40	−47.25

* t_f = temperature of fusion.

Hg-Pb

For Ag, ρ_0 = 1.54 (298)

Pb	ρ_t	t
0.01	93.85	13.2
0.025	93.7	13.05
0.05	93.6	13.2
0.1	93.35	12.3
0.1995	92.77	13.4
0.4975	91.27	13.1

Hg-Pb.—(*Cont'd*)

Pb	ρ_t	t
0.99	89.1	13.15
1.96	87.5	13.15
3.84	86.27	13.2

Pb (284)	ρ_t/ρ'	t
0	1.000	266.6
5.94	0.7853	263.7
12.07	0.7150	264.0
24.81	0.6852	264.0
32.83	0.6860	263.7
48.12	0.7150	263.4
51.45	0.7219	264.5
59.46	0.7426	264.1
70.73	0.7654	264.9

Pb (159)	ρ_t	t
0.03	95.25	17.0
0.06	95.1	18.0
0.121	94.7	16.1
0.182	94.4	16.6
0.269	93.9	16.8
0.358	93.4	16.9
0.52	92.6	16.7
0.69	91.8	17.7
0.863	91.0	17.0
1.009	90.3	17.1
1.182	89.65	15.9
1.354	89.05	16.2
1.53	88.7	16.7
1.70	88.6	16.7

Pb	a	b
0.69*	1.0400	28
1.354*	1.0714	59
1.70*	1.0855	82
Sat.†	1.0554	1270

* Unsaturated; $t \gtrless 80°$.
† Saturated; $17° \gtrless t \gtrless 24°$.

Pb (83)	ρ_0
0.259	92.51
0.518	91.24
1.036	89.66
1.554	88.80
2.072	88.22

Pb	ρ_{18}	α	Lit.
0.241		1.109	(18)
0.481		1.110	(18)
0.957		1.111	(18)
0.249	94.1	0.86	(282)
0.498	92.9	0.75	(282)
0.990	90.65	0.87	(282)

Hg-Pb-Bi; *v.* Hg-Bi-Pb

Hg-Sn

Sn	ρ_t	t
For Ag, $\rho_0 = 1.54$ (298)		
0.01	93.7	12.15
0.025	93.6	12.5
0.05	93.3	12.7
0.1	92.8	13.1
0.1995	91.7	13.2
0.4975	88.85	13.1

Hg-Sn.—(*Cont'd*)

Sn	ρ_t	t
0.99	86.9	13.2
1.96	83.2	13.0
3.84	77.8	12.8
For Hg, $\rho_{18} = 95.59$ (184)		
0.01	95.4	18.4
0.02	95.3	18.0
0.05	94.95	18.2
0.1	94.4	18.8
0.2	90.55	19.0
0.5	90.4	18.4
0.99	87.85	18.6
1.94	84.55	18.8
3.84	78.8	19.0

Sn (284)	ρ_t/ρ'	t
0	1.000	247.2
4.09	0.7553	245.3
6.38	0.6990	245.2
10.74	0.6403	246.2
19.50	0.5889	246.2
24.30	0.5840	246.0
33.71	0.5636	247.4
36.01	0.5375	245.6
48.64	0.5269	245.7
54.10	0.5016	246.4
59.62	0.4951	246.0
66.33	0.4829	247.7
71.54	0.4730	247.2
79.11	0.4690	247.2
88.13	0.4535	246.2
100.0	0.4282	247.2

Sn	ρ_{18}	α	Lit.
0.498	90.0	0.900	(282)
0.990	88.0	0.979	(282)
0.990		1.095	(18)
1.67		1.103	(18)
1.96		1.111	(18)

Sn (83)	ρ_0
0.148	92.32
0.297	90.74
0.594	89.02
0.890	87.90
1.187	86.80

For Hg, $\rho_0 = 94.07$, $\rho_{20} = 95.76$ (159)

Sn	ρ_t	t
0.054	95.05	20.0
0.12	94.35	20.3
0.211	93.25	20.8
0.353	91.85	21.5
0.457	90.85	21.5
0.533	90.1	21.2
0.613	89.35	21.2

Sn	a	b
0.211*	1.0265	44
0.457*	1.0544	56
0.702*	1.0795	88
0.787*	1.0885	90
Sat.†	1.0414	1850

* Unsaturated; $t \gtrless 80°$C.
† Saturated; $17° < t < 25°$.

Hg-Sn.—(*Cont'd*)
R is "relative" value of ρ_t (282)

t	R
Sn = 2%	
15.7	8634
91.1	9410
83.2	9330
79.6	9301
69.6	9220
60.7	9152
48.5	9040
39.4	8991
34.8	8961*
Sn = 3%	
15.8	7608
92.4	8841
79.5	8761
71.1	8731
60.8	8671
50.0	8612
38.9	8598
29.5	8560
16.3	8516
Sn = 4%	
15.2	9122
68.7	9129
76.1	9536
81.4	9583
91.5	9516
85.4	9471
79.6	9226
74.0	9179
69.0	9136
62.6	8930
58.6	8926
52.3	8883
38.7	8823
22.6	8779
Sn = 5%	
19.2	8118
89.3	8369
76.2	8334
69.7	8288
59.6	8242
52.0	8220
36.9	8187
19.5	8151
19.7	8110
Sn = 6%	
14.9	7997
50.7	8117
82.3	8225
89.2	8347
90.7	8442
91.0	8424
73.4	8319
61.6	8259
50.3	8231
32.5	8180
22.2	8131
16.4	8106
15.4	8101

Hg-Sn.—(*Continued*)

t	R
Sn = 12%	
17.0	1639
34.0	1655
45.0	1656
62.0	1657
84.0	1695
86.0	1725
90.6	1805
92.8	1877
93.8	1877
86.0	1866
83.3	1863
77.5	1795
75.8	1785
70.8	1770
65.0	1759
55.8	1749
48.6	1744
34.3	1725
17.2	1704

* Suddenly cooled, $\rho_{16.1} = 8924$; after 3 hr, $\rho_{16.6} = 8920$; after 20 hr, $\rho_{17.0} = 8801$.

Hg-Tl (210)

Tl	ρ_0	α_0*
0	94.07	0.96
10	80.65	0.77
15.3	74.52	0.63
18.3	72.99	
19.2	65.83	5.66
20.5	55.65	
22.1	46.25	
23.7	37.5	
24.6	32.8	61
26.6	31.8	
27.2	31.6	63.5
27.9	31.6	
29.3	31.8	61.8
30.6	32.1	
31.4	32.5	59
33.1	32.7	57.5
36.6	32.1	58.5
39.5	31.8	58.4

* $0° < t < 19°$.

Tl	ρ_{75}	α_0*
0	18.8	
0.6	19.5	
0.8	20.6	
1.6	20.0	
5.4	21.9	
11.6	29.4	
19.2	30.9	
20.8	29.9	
22.6	27.8	
24.6	25.7	3.73
25.5	25.3	
26.6	24.8	3.71
28.2	24.8	3.71
31.4	25.4	3.77
33.5	25.0	
36.6	24.5	4.19
39.5	24.1	4.32

* $0° < t < 75°$.

Hg-Tl.—(*Cont'd*)

Tl (23)	ρ_{50}	α_{50}	β_{50}
1.0	96.58	0.872	1.241
2.89	93.20	0.814	1.029

Hg-Zn

Zn	ρ_t	t
For Ag, $\rho_0 = 1.54$ (298)		
0.01	93.7	13.07
0.025	93.5	13.07
0.05	93.2	13.13
0.1	92.45	13.07
0.1995	91.15	13.13
0.4975	87.6	13.2
0.99	82.27	13.27
1.96	75.5	13.0
3.84	69.9	13.1
For Hg, $\rho_0 = 94.07$, $\rho_{20} = 95.76$ (159)		
0.0095	95.3	17.0
0.019	95.2	18.0
0.038	94.75	16.1
0.057	94.5	16.6
0.085	94.1	16.8
0.113	93.65	16.9
0.165	92.9	16.7
0.22	92.3	17.7
0.275	91.45	17.1
0.32	90.85	17.1
0.375	90.15	15.9
0.43	89.4	16.0
0.49	88.85	16.7
0.54	88.15	16.5
0.605	87.4	16.8
0.625	87.15	16.9
0.70	86.15	17.0
0.755	85.9	20.1
0.815	85.4	21.3
0.926	84.1	20.1
1.038	82.9	20.2
1.147	81.8	20.1
1.227	81.1	20.0
1.335	80.05	19.9
1.429	79.2	20.0
1.538	78.3	19.6
1.607	77.7	19.7
1.703	77.0	19.7
1.765	76.4	19.6
1.844	75.9	19.4
1.880	75.4	19.4
2.007	74.8	19.4
2.065	74.7	19.6

Zn	a	b
0.219*	1.0347	19
0.432*	1.0667	13
0.713*	1.1074	28
1.43*	1.2071	68
1.648*	1.2350	107
Sat.†	1.1724	5410

* Unsaturated; t 80°C; heating to 80°C reduces the ratio; for 0.713 % Zn the reduction is the greatest and = 0.2 %.

† Saturated; $17° < t < 22°$; at 23.3°C, ratio is about 0.3 % less than computed.

Hg-Zn.—(*Cont'd*)

Zn	ρ_t	α
t = 0°C (83)		
0.163	91.70	
0.327	89.56	
0.654	85.59	
0.980	82.15	
t = 18°C (282)		
0.249	94.0	0.80
0.498	90.45	0.88
0.990	86.9	0.97

Zn	α	Lit.
0.761	1.094	(18)
1.51	1.089	(18)
16.5	1.876*	(293)
23.9	1.850*	(293)
28.3	1.814*	(293)
33.3	1.844*	(293)
40.1	1.807*	(293)

* Mean 30 to 100°C.

In-Pb (158)

Pb	ρ_{25}	α^*
0	9.913	4.38
16.8	16.52	2.75
31.1	24.28	2.45
54.6	27.79	2.28
64.4	31.92	2.25
73.0	32.66	2.33
86.4	30.98	2.71
94.2	28.27	2.75
97.1	25.41	3.44
99.2	22.83	4.00
100.00	21.50	4.24

* 25 to 100°C.

K-Na (203); *v. also* Table 3

Na	ρ_{20}	α_{20}*
53	33.8	1.47

* 46 to 125°C.

K-Rb (152)

Rb	ρ_0	ρ_{25}	ρ_{50}*
0.00	6.60	7.71	8.82
26.7	8.29	9.49	10.72
39.7	9.05	10.34	16.89
54.9	10.17	11.64	19.01
74.0	11.32	12.92	21.14
85.6	11.60	13.41	22.28
90.0	11.57	13.50	22.58
100.0	11.29	13.16	23.15

Rb	ρ_{75}	ρ_{100}
0.00	14.43	15.80
26.7	17.46	18.98
39.7	18.42	19.84
54.9	20.75	22.53
74.0	22.88	24.75
85.6	24.16	26.05
90.0	24.58	26.39
100.0	25.32	27.47

* Note break between 26.7 % Rb and 39.7 % Rb.

K-Tl; *v.* Table 3

Mg-Ag; *v.* Ag-Mg

Mg-Al; *v.* Al-Mg

Mg-Cd; *v.* Cd-Mg

Mg-Cu; *v.* Cu-Mg

Mg-Pb (264); *cf.* (265)

Pb	ρ_{25}	α^*
0	4.40	4.10
6.00	9.00	1.70
13.20	9.00	1.70
21.00	16.60	0.80
23.20	17.70	0.87
47.37	28.00	0.65
67.00	46.00	1.23
69.68	59.00	1.10
70.90	68.00	1.00
73.77	107.0	0.95
75.17	97.0	1.50
75.50	103.5	1.20
76.00	109.0	1.55
78.11	129.0	1.80
79.00	148.5	2.05
80.10	163.0	1.80
80.30	180.0	1.20
81.80	149.0	2.20
83.30	159.0	2.59
85.00	121.0	2.20
85.50	114.0	2.45
89.27	73.50	2.53
91.66	55.00	2.90
94.60	46.50	2.84
97.25	36.70	2.80
98.4	30.70	3.35
100.0	21.07	4.29

* $25° < t < 100°$.

Mg-Sn (265)

Sn	ρ_{25}	Δ_{100}
5.5	6.75	1.63
11.2	11.9	1.50
15.3	14.63	1.00
20.0	15.65	1.37
35.2	17.61	2.04
55.5	42.18	1.98
68.9	225	2.24
69.0	413.0	2.76
69.0	430.0	3.01
70.5	463.0	2.75
71.1	1096.0	4.45
72.5	445.0	4.30

Mg-Sn.—(*Cont'd*)

Sn	ρ_{25}	Δ_{100}
72.9	260.0	4.27
73.9	283.0	4.36
78.0	161.4	4.28
88.2	35.68	4.46
90.0	37.26	4.49
91.4	30.01	4.45
95.1	21.18	4.31
97.9	15.96	4.43

Mg-Zn (265)

Zn	ρ_{25}	Δ_{100}
14.3	7.175	2.67
52.9	11.0	2.27
56.5	15.13	2.04
67.6	15.54	2.02
70.1	26.78	1.37
80.1	31.12	0.97
84.4	15.88	2.89
86.25	16.90	2.63
86.45	14.2	3.20
91.5	12.51	3.13
96.0	7.8	3.79

Mn-x; *see* the other metal

Mo-W (82)

W	a
0	4.57
5.8	4.08
11.5	3.75
22.7	3.37
33.5	3.14
43.9	2.99
55.8	2.91
63.7	2.92
73.2	3.04
82.4	3.26
91.4	3.76
94.76	4.01
98.10	4.37
98.49	4.43
98.85	4.46
99.255	4.56
99.618	4.64
100	4.82

Na-Cd; *v.* Table 3

Na-Hg, Na-K; *v.* Hg-Na, K-Na

Na-Pb, Na-Sb, Na-Tl; *v.* Table 3

Ni; for effect of traction and of magnetic field, *v.* Fe-Ni

Key or name	Impurities, 1/100 %					
	Co	Cu	Fe	Mn	Si	C
1						3.5
2	99					
3	15	20	tr.		0	0
4	tr.	80	tr.		20	
Elec. Ni		5	15			
Grade A		24	65	8	3	8
5	10	40	60		15	
6	50	tr.	150		10	

Ni.—(*Continued*)

Key or name	Impurities, 1/100 %					
	Co	Cu	Fe	Mn	Si	C
7	136	15	44	104	6	
Grade C		40	89	210	18	22
Grade D		16	74	475	13	8

Grade	Elec.	A	C	D
t (134)	ρ	ρ	ρ	ρ
20	9.74	10.64*	13.97†	17.80‡
100	14.2	15.21	18.99	22.95
200	20.16	21.92	26.54	29.90
300	27.86	30.1	36.04	37.38
400	35.94	37.44	42.16	41.11
500	38.95	41.15	45.51	43.78
600	41.97	44.12	48.72	46.64
700	45.0	47.24	52.09	49.49
800	48.0	50.31	55.29	52.31
900	51.03	53.61	58.91	55.70
1000	54.91	57.24	62.84	59.10

* α = 5.37 (65). † *Cf.* (133). ‡ By (133), ρ_{20} = 19.43.

Key	ρ_0	α	β	Lit.
1	7.7			(237)
2	8.38*	5.21		(136)
3†	9	5.3‡	5.5‡	(214)
4	10.24	3.7‡	6.0‡	(214)
5	14.25	3.5‡	7.0‡	(214)
6	13.25	3.0‡	7.0‡	(214)
7	11.76§	Δ_{100} = 4.4		(139)

* t = 20°C. † Δ_{100} = 5.8 (214). ‡ From 0 to 345°C. § t = 18°C.

Ni-Al (136); *cf.* **Al-Ni**

Al	α	Al	α
0.498	3.68	0.99	2.85

Ni-C; *v.* **Ni**

Ni-Co; *v.* **Ni** and **Co-Ni**

Ni-Co-Fe-(Mn, Mg, Si, Cu)

Co	Fe	Mn	Mg	Cu	Si	ρ_{20}	α	Lit.
0.97	0.97	0.97				9.41	4.59	(136)
0.98	0.98					8.82	4.90	(136)
1.06	0.36	1.22	0.11	0	0.07	11.5*		(288)
1.18	0.37		0.12		0.08	9.9†		(288)
1.15	0.43		0.11	0.1	0.08	9.5‡		(288)
1.36	0.44	1.04		0.15	0.06	11.76§	4.4	(139)

* Same for forged as for cast. † Forged. ‡ Cast. § For 18°C.

Ni-Cr (135)

Cr	ρ_{20}	α
0	10.67	6.00
4.76	45.7	0.970
9.1	67.8	0.370
10	*v.* **Ni-Cr-(Fe, Mn)**	
13.04	84.1	0.200
15	*v.* **Ni-Cr-(Fe, Mn)**	
16.67	96.9	0.120
18.3	*v.* **Ni-Cr-(Fe, Mn)**	
20	99.7	0.140
20	*v.* **Ni-Cr-(Fe, Mn)**	

Ni-Cr-Cu; *v.* **Cu-Ni-Cr**

Ni-Cr-Fe; *v. also* **Fe-Ni-Cr** and **Ni-Cr-(Fe, Mn)**

Cr	Fe	ρ (200)
3	4	46.0
6	4	53.0
7	18	83.1
10	35	107.0
13	16	100.2
15	5	96.8
20	25	93.5
25	20	113.0
29	7	110.0
32	10	110.0
37	11	113.0

Ni-Cr-Fe.—(*Continued*)

Alloy No. 3 (134); Cr, 31.35; Fe, 13.77; Mn, 0.00

t	ρ	t	ρ
20	114.1	700	123.15
300	119.6	800	123.4
400	121.0	900	124.4
500	122.7	1000	125.3
600	122.75		

Ni-Cr-(Fe, Mn), Nichromes; *cf.* **Fe-Ni-Cr**

	Cr	Fe	Mn	Lit.
Nichr	12	28	0	(65)
Nichr	11.3	26.3	1.5	(134)
Nichr. II	18.7	10.53	1.58	(134)
Nichr. III*	15	0	0	(65)
Nichr. III*	15.3	0	0	(134)
Nichr. IV†	20	0	0	(65)
Nichr. IV†	18.3	0	0	(134)
Excello	14	0.5	0.5	

	Nichr.	Nichr. II	Nichr. III	Nichr. III*
Lit.	(65, 134)	(134)	(65)	(134)
t	ρ	ρ	ρ	ρ
20	109.75	110.7	89.75	97.15
100	112.25		90.75	
200	115.4		92.1	
300	118.1	114.8	93.4	101.3
400	119.9	116.2	94.75	102.5
500	121.4	117.6	95.75	103.5
600	122.2	117.2	95.75	103.4
700	121.4†	117.1	96	103.75
800	123.7	117.4	97.1	104.4
900	125	118.2	98.1	105.7
1000	126.9	119.0	99.75	107.2
α	*v. infra*	0.2–0.15 (65)	0.050‡ (175)	

Nichrome IV§

t	ρ (65)	ρ (134)	t	ρ (65)	ρ (134)
20	103	98.0	600	108.5	101.85
100	104.9		700	108	101.65
200	106		800	108.9	101.85
300	106.9	100.75	900	109.4	102.35
400	108	101.75	1000	110.6	103.5
500	108.9	102.6	α	0.179 (65)	

* Kromore. Same nominal composition as Rayo, α = 0.102 (65).
† ρ_{700} = 122.8 (134).
‡ t = 20 to 50°C; for t = 20 to 100°C, α = 0.187 (65).
§ Chromax. Same nominal composition as Chromel A, α = 0.11 (130), and Karma, α = 0.095 (65).

(260)	Nichr.*	Excello	(260)	Nichr.*	Excello
t	α	α	t	α	α
25	0.32	0.22	575		0.15
50	0.30	0.23	600	0.05	0.11
100	0.30	0.26	650	0.05	0.09
150	0.38	0.29	700	0.06	0.11
200	0.46	0.29	750	0.07	0.13
250	0.50	0.27	800	0.07	0.15
300	0.56	0.21	850	0.08	0.17
325	0.43		900	0.10	0.22
350	0.38	0.22	950	0.14	0.26
400	0.30	0.24	1000	0.18	0.29
450	0.24	0.25	1050	0.28	0.32
500	0.24	0.26	1075	0.36	
550	0.12	0.20			

* At 20°C, α = 0.43 (135); 20 to 50°C, α = 0.026 (175); 20 to 100°C, α = 0.2 (65).

Ni-Cr-(Fe, Mn).—*Continued*

Co	Calido (65)	ChP	Chromel P (130)
Ce	Calorite	Eo	Excello (40, 260)
	Chromel A, *v.* Nichrome IV		Karma, *v.* Nichrome IV
			Rayo, *v.* Nichrome III
ChC	Chromel C (130)	Tt	Tophet

	Cr	Fe	Mn	ρ	α
Co	8–16	24–25	(?)	110	0.12
ChP	10	0	0	70.6	0.54
Tt	10	26	3	107	
ChC	11	25	0	109	0.18
Ce	12	15	8	110	
Eo	14	0.5	0.5	92	0.16

Ni-Cu; *v.* **Ni-Cu-Zn and Cu-Ni**

Ni-Cu-Co; *v.* **Ni**

Ni-Cu-Cr; *v.* **Cu-Ni-Cr**

Ni-Cu-Fe-Mn-(Si, C), Monel metals; *v.* **Cu-Ni-Fe-Mn-(Si, C)**

Ni-Cu-Mn; *v.* **Cu-Ni-Mn**

Ni-Cu-Mn-Fe; *v.* **Cu-Ni-Fe-Mn**

Ni-Cu-Ti; *v.* **Cu-Ni-Ti**

Ni-Cu-Zn (281); *cf.* **Cu-Ni-Zn**

Cu	Zn	ρ_{20}
0	0	11.9*
0	11.0	23.8
0	14.3	28.4
0	21.8	36.4
0	29.2	42.3
5.4	0	31.1
3.2	11.0	31.7
4.2	22.8	42.3
5.2	31.2	55.5
4.2	32.2	56.2
7.3	21.7	73.4
10.8	0	64.1
10.5	10.3	62.8
10.5	13.1	103.1
10.4	31.0	128.3
17.0	0	121.7
14.8	7.7	126.9
13.6	19.4	126.9
27.5	0	179.2
25.2	7.6	177.8
24.2	11.4	177.2
22.0	11.9	180.5
19.7	24.6	177.2
32.2	10.8	248.6
44.7	7.5	304.0

* Assumed as basis.

Ni-Fe, *v.* **Fe-Ni**

Ni-Fe-Cr; *v.* **Fe-Ni-Cr, Ni-Cr-Fe, and Ni-Cr-(Fe, Mn)**

Ni-Fe-Mn; *v.* **Fe-Ni-Mn**

Ni-Fe-Mn-Cu-(Si-C); *v. also* **Ni-Mn-Fe-Cu**

Alloy No. 141 (134); *cf.* (133) Fe, 28.86; Mn, 1.30; Cu, 0.16; Si, 0.13, C, 0.22

t	ρ
20	22.34
100	31.28
200	43.11
300	56.72
400	71.50
500	88.45
600	106.75
700	110.30
800	113.00
900	116.20
1000	119.05

Ni-Mn-(Fe) (135); *v. also* **Fe-Ni-Mn**

Mn	ρ	α
0	12.43	6.22
4.76	17.4	2.97
7.4	23.3	2.49
9.1	28.0	
11.1	36.4	
13.04	41.6	
16.67	51.2	
85	70.0*	1.3*

* From (148); α holds from 20 to 100°C.

Mn	ρ_{20}	α	Lit.
0		5.56	(134)
0.249		4.60	(136)
0.626		4.52	(136)
0.99		3.57	(136)
5	19.96	1.0	(194)
4.2	17.4	2.97	(250)
7.4	23.3	2.49	(250)
1.5–2.0	13.95	3.6	(65)
4.2–5.0	21.6	3.6	(65)

All	Alumel (130).
MN	Manganese nickel (65).
Mno	Magno (40, 65).

	Mn	Fe	ρ	α
MN	1.5–5	(?)	15	
All	2.5	0.5	33.3	1.2
Mno	5	0	20.0	0.005

Ni-Mn-Fe-Cu

Mn	Fe	Cu	ρ_{20}	α	Lit.
0.1	0.65	0.25	10.63	5.37	(133)
2.1	0.9	0.4	13.95		(133)
4.75	0.75	0.2	19.43		(133)
0.59	0.14	0.03	9.12	4.90	(136)

Ni-Ti (132, 188)

Ti	ρ	α
2	24.7	1.9
2	30.3	1.72
5	53.5	0.77
10	66.6	

Ni-Zn; *v.* **Ni-Cu-Zn**

Pb-Ag; *v.* **Ag-Pb**

Pb-Au (182)

Au	ρ_t	t
8.7	26.4	25.4
15.85	35.7	23.0
19.2	41.0	26.1
24.1	54.4	19.7
32.2	51.2	22.3
48.7	42.9	16.8

Pb-Bi; *v.* **Bi-Pb and Table 3**

Pb-Cd; *v.* **Cd-Pb and Table 3**

Pb-In; *v.* **In-Pb**

Pb-K; *v.* **Table 3**

Pb-Mg; *v.* **Mg-Pb**

Pb-Na; *v.* **Table 3**

Pb-Sb (182); *v. also* **Table 3**

For Ag, $\rho_0 = 1.54$

Sb	ρ_t	t
2.31	21.7	23.7
5.63	23.2	25.5
10.56	25.55	25.4
16.45	27.9	26.1
23.05	32.6	24.1
37.1	39.2	23.4
54.1	46.5	26.3
70.3	53.9	24.2

Pb-Sn (182, 188, 189); *v. also* **Table 3**

For Ag, $\rho_0 = 1.54$

Sn	ρ_t	t
8.5	18.94	18.6
12.4	18.59	9.1
22.8	17.68	16.0
35.9*	16.57	15.0
52.8	15.17	15.9
69.1	14.56	16.2
77.0†	14.28	18.6

* $\rho_0 = 14.77$; $\alpha_0 = 3.78$; $\beta_0 = 5.91$ (189).

† $\rho_0 = 12.31$; $\alpha_0 = 3.886$; $\beta_0 = 6.41$ (189).

Pb-Tl (103)

Tl	ρ_0	α_0	β_0
0	16.6	4.27	1.512
3.45	19.15	3.67	1.362
4.5	19.26	3.62	1.474
7	20.8	3.32	1.500
14	26.8	2.51	1.086
22	33.35	1.942	1.030
32	37.8	1.655	1.08
42	40.1	1.523	1.095
54	39.2	1.499	1.025
63	36.6	1.526	1.14
67	34.2	1.629	1.263
70	31.9	1.707	1.445
75	28.3	1.884	1.67
77.5	25.7	2.14	1.75
80*	23.8	2.30	1.78
85*	20.8	2.68	2.38
89.9*	19.2	2.96	3.11
90.0*	18.9	3.03	3.34
93.5*	19.04	3.00	3.53
95.0*	18.13	3.19	3.92
96.5*	16.81	3.41	3.86
98.0*	15.50	3.68	3.81
99.5*	14.23	4.02	3.42
100.0*	13.80	4.16	2.30

* β-form.

Pb-Tl.—(*Continued*)

Tl (158)	ρ_{25}	α^*	Tl(158)	ρ_{25}	α^*
0	21.50	4.24	79.76	23.86	2.78
4.85	24.52	3.67	89.86	20.09	3.40
9.8	27.37	2.97	92.89	19.63	3.75
24.7	33.52	2.23	94.93	19.59	3.71
39.60	37.48	1.98	95.43	20.40	3.97
49.61	38.31	1.78	96.45	21.52	3.55
59.63	36.95	1.72	96.95	22.90	4.27
66.33	34.11	1.85	97.97	20.76	4.04
69.67	31.79	1.91	98.99	19.43	4.42
74.72	28.12	2.19	100	18.25	4.78

* 25 to 100°C.

Pb-Zn; *v.* Table 3

Pd-Ag, Pd-Au, Pd-Pt; *v.* **Ag-Pd, Au-Pd, Pt-Pd**

Pt-Ag; *v.* **Ag-Pt**

Pt-Ir (140)

Ir	ρ_{25}	α^*
1	12.51	3.23
2.5	14.66	2.61
5	18.23	2.03
10	24.39	1.38

* 25 to 100°C.

Ir	ρ_0	α^* (81)
0	10.07	3.48
5	17.82	1.88
10	23.05	1.26
15	26.9	1.02
20	29.5	0.81
25†	31.55	0.66
30	32.9	0.58
35	36.9	0.58
	(10)	
0	9.766	3.940
10	25.397	1.150
15	28.650	0.928
20	33.16	0.739
100	8.19	2.93
19.9	30.90‡	0.822‡

* 0 to 160°C.
† $\Delta_H = 0.5$ if $t_A = 950$°C (112).
‡ From (76); Pt_4Ir.

20% Ir (63); *cf.* (62)

t^*	ρ_t
−197.1	26.031
−106.1	28.347
− 81.9	28.836
0	30.896
+ 1.8	30.933
16.1	31.296†
93.3	33.271

* Pt scale of t. † $\alpha_{15} = 0.822$.

Ir	α	β	Lit.
6	1.453	−1.576	(173)
10	1.177	−0.1086	(173)
10	1.5		(144)
15	0.782	−0.02106	(173)
20	1.048	−0.3683	(173)

Pt-Pd (140)

Pd	ρ_{25}	α
1	11.98	3.38
2.5	13.47	2.94
5	15.61	2.46
10	19.50	1.80
Pd (81)	ρ_0	α^*
0	10.06	3.48
10	18.6	1.36
20	23.38	1.18
30	25.65	1.00
40	26.45	0.96
50	25.72	1.03
60	24.26	1.04
70	21.87	1.28
80	18.92	1.55
90	14.43	2.14
100	10.58	3.28

* 0 to 160°C.

Pt-Rh (140)

Rh	ρ_{25}	α
1	12.56	3.26
2.5	14.34	2.71
5	16.77	2.17
10	21.853	1.47

Rh	ρ_0	α	Lit.
10	22.45	1.35	(10)
10	21.1	1.7	(144)
9.1		0.350	(162)
10	21.14	1.43	(76)

10% Rh (63); *cf.* (62)

t^*	ρ_t
−197.1	15.134
−106.1	18.065
− 81.9	18.648
0	21.142
+ 1.75	21.188
16.15	21.635†
92.25	23.943

* Pt scale of t. † $\alpha_{15} = 1.43$.

Rb-K; *v.* **K-Rb**

Sb-Cd, Sb-Cu, Sb-Pb; *v.* **Cd-Sb, Cu-Sb, Pb-Sb**

Sb-Se (215), 45.2% Se

Treatment	ρ_{17}
Q in H_2O.....	56 000
Q in air.....	11 300
A.....	9 400

Sb-Se.—(*Cont'd*)
47.5% Se = Sb_5Se_7
First cycle

t	ρ_t	t	ρ_t
15	198 000	382	319 000
124	225 000	339	346 000
182	243 000	317	351 000
313	292 000	246	346 000
360	301 000	157	297 000
414	279 000	15	221 000
440	265 000		

After 10 cycles

t	ρ_t
15	887 000
161	864 000
385	584 000
440	376 000

49.3 Se = Sb_2Se_3

t	ρ_t
23	2010×10^6
50	555×10^6
110	59×10^6
518	0.9×10^6

Sb-Sn, Sb-Te; *v.* **Sn-Sb, Te-Sb**

Sb-Zn (180)
For Ag, $\rho_0 = 1.54$

Zn	ρ_{25}
33.33	373

Si-Fe-Al (33)

Fe	Al	ρ_{12}
3.78	0.43	470 000
14.42	0.42	240 000
8.67	0.65	154 000
11.35	0.53	118 000
6.67	1.02	82 000
11.16	1.25	95 000

Sn-Ag, Sn-Al, Sn-Au, Sn-Bi; *v.* **Ag-Sn, Al-Sn, Au-Sn, Bi-Sn**

Sn-Cd, Sn-Cu, Sn-Hg; *v.* **Cd-Sn, Cu-Sn, Hg-Sn**

Sn-K; *v.* Table 3

Sn-Mg; *v.* **Mg-Sn**

Sn-Na; *v.* Table 3

Sn-Pb; *v.* **Pb-Sn**

Sn-Sb; *v. also* Table 3

Sb (151)	ρ_{25}	α
0	10.39	3.85
1	11.91	
4	14.1	
6	14.88	3
8	15.48	
10	17.61	2.72
12	17.67	
20	19.68	3.11
30	22.94	3.25
35	23.26	3.48
39.27	25.38	3.53
41	24.04	3.61

Sn-Sb.—(*Cont'd*)

Sb (151)	ρ_{25}	α
43	26.52	
43.5	29.07	3.44
44	29.67	3.40
46	31.25	2.82
49	30.0	2.91
50	28.57	3.43
51	29.76	
52	32.26	2.77
53	31.95	
54	32.26	
56	32.57	2.62
58	34.48	2.25
60	38.02	1.81
67	39.22	
70	43.47	
75	46.73	1.69
80	49.5	1.63
90	54.64	1.62
95	50.76	3.90
100	43.67	5.03

For Ag, $\rho_0 = 1.54$ (182)

Sb	ρ_t	t
1.04	15.43	27.9
2.06	16.02	25.7
5.01	18.14	27.0
9.55	20.0	27.4
17.4	21.36	22.4
26.0	22.48	20.4
34.04	25.37	20.7

Sn-Te (119)

Te	ρ_{18}
10	15.23
20	32.45
30	48.5
40	68.5
50	97.1
48.1*	103
55	145
60	204
65	238
70	322.8
80	1491
90	2780

* TeSn.

Sn-Zn; *v. also* Table 3
For Ag, $\rho_0 = 1.54$ (182, 188, 189)

Zn	ρ_t	t
8.5	12.16	21.3
12.3	11.56	20.0
21.9	10.07*	20.0
36.0	8.88	19.9
52.9	7.83	21.1
69.2	6.91	20.1

* $\rho_0 = 9.12$; $\alpha = 3.884$; $\beta = 6.35$ (189).

Te-Ag* (230)

t	ρ_f†	ρ_A†
	2% Ag	
330	17.6	17.6
280	22.9	22.9
230	31	31
185	*41.6*	43.6
129.5	28.6	72.4
75	23.1	131.6
+21	18.3	*182.7*
−30		156
−94		118.5
	4% Ag	
330	18.2	18.2
260	28	28
200	41.9	41.7
179	*50*	50.5
120.5	33.3	94
71	28.3	180
+10		*275*
− 7		271
−15		*278*
−63		244
	20% Ag	
290	22.4	22.4
230	38.3	38.3
200	49.9	49.0
180	58.0	59.2
80	87	265
+30	88	419
−97	144	1520

* *See also Tables Annuelles*, **3**: 264; 1912. Italic numbers are apparently maxima.

† Resistivity when cooled from melting point to t, rapidly (ρ_f), slowly (ρ_A).

Te-Sb (119)

Sb	ρ_{18}
5	2000
10	1820
20	1136
25	625
30	500
35	345
38.9*	208.3
40	263.2
50	286
60	345
70	435
80	526

* Te_2Sb_2.

Te-Sn; *v.* Sn-Te

Tl-Bi; *v.* Bi-Tl

Tl-Cd (190)

Cd	α_0	β_0
5	3.673	6.94

Tl-Pb; *v.* Pb-Tl

Tl-Sn (190)

Sn	α_0	β_0
5	3.120	2.97

W-Fe, W-Mo; *v.* Fe-W, Mo-W

Zn-Al, Zn-Cd, Zn-Cu, Zn-Mg, Zn-Pb, Zn-Sn; *v.* Al-Zn, Cd-Zn, Cu-Zn, Mg-Zn, Pb-Zn, Sn-Zn

Named alloys of unstated composition

t	ρ_t	α_0	Range, °C
	American nickel (3)		
25	72.92	5.16	25–200
200	138		
400	214	1.22	400–1000
700	269		
1000	319		
	Beacon alloy		
60–80	0.7		
	Extra Prima (66, 141)		
0	29.35	0.28	17
	Ferrozoid (160)		
	84		
	Ferry (160)		
	47.2		
	Krupp (a Ni-steel) (135)		
20	85	0.70	20
	Mangaloy (175)		
20	107	0.073	20–50
	New Metal (141)		
0	51.1	−0.038	17
	Resista		
	76	1.1	
	Rheostene (a Ni-steel)		
	77	1.2	
	Superior (46, 60, 141, 260)		
0	81.0	1.15	17
15	87.2	0.81	

Superior (260)

t	α
25	0.96
50	0.92
100	0.84
150	0.76
200	0.68
250	0.60
300	0.49
350	0.42
400	0.41
450	0.40
500	0.39
550	0.38
600	0.36

Superior.—(*Cont'd*)

t	α
650	0.32
700	0.29
750	0.27
800	0.26
850	0.25
900	0.25
950	0.25
1000	0.24
1050	0.24

Tarnac (67, 160)

t	ρ_t	α_0	Range
(?)	41	0.025	20°

TABLE 3.—RESISTIVITY OF NON-MERCURIC ALLOYS AT TEMPERATURES NEAR AND ABOVE THEIR NORMAL MELTING POINTS

The mercuric alloys Hg-K and Hg-Na for which data are available for a considerable range of t, are here included; for others, *see* Table 2.

When neither the initial nor the final temperature is the same for every member of a given system but ρ is recorded for some intermediate temperature that is common to every member, then that ρ and the corresponding temperature are printed in bold face; if two are required, the second is in italics.

Unit of $\rho = 1$ microhm-cm $= 10^{-6}$ ohm-cm, of $D = 0.01$ microhm-cm per 1°C; temperature is t,°C.

Al-Cu* (24)

t	ρ_t
	0% Cu
700	27.80
D =	+1.467
1300	36.68
1100	**33.68**
	5% Cu
700	28.05
D =	+1.723
1300	38.39
1100	**34.96**
	19.67% Cu
600	30.87
D =	+0.814
1300	36.57
1100	**34.95**
	32.84% Cu
600	39.03
D =	+1.386
1300	48.73
1100	**45.97**
	50% Cu
600	45.45
D =	+0.554
1300	49.33
1100	**48.22**
	55% Cu
600	48.32
D =	+0.263
1300	50.16
1100	**49.64**

Al-Cu.*—(*Cont'd*)

t	ρ_t
	70% Cu
800	65.44
D =	+0.096
1300	65.92
1100	**65.70**
	77.72% Cu
1000	72.30
1100	**70.27**
1200	68.47
1300	66.95
	82% Cu
1000	72.30
1100	**70.08**
1200	68.00
1300	66.22
	85% Cu
1100	**66.72**
D =	−1.05
1400	63.57
	87.7% Cu
1100	**62.50**
	90% Cu
1100	**58.22**
D =	−0.41
1300	57.40
	95% Cu
1100	**43.18**
1200	43.33
D =	+0.24
1400	43.81
	100% Cu
1100	**21.52**
D =	0.883
1400	24.17

* Values of ρ appear to be too high.

Bi-Cd-Pb-Sn
Wood's metal (283)
Bi, 55.74; Cd, 16.80; Pb, 13.73; Sn, 13.73

t	ρ_t
122.8	110.3
96.8	106.9
89.0	104.7
85.0	101.6
77.4	95.0
74.7	93.25
69.8	88.8
65.2	66.4
65.0	60.75
57.7	60.1
52.2	59.1
49.0	58.5
41.8	57.85
33.0	56.4
17.8	54.4
9.8	52.6
0.0	51.7
24.0	54.3
34.2	55.3
45.7	56.9
50.3	57.7
57.1	58.4
65.0	60.0
67.3	60.2
68.7	60.4
70.2	61.0
71.4	62.6
73.0	63.95
74.5	87.4
75.0	88.7
75.5	89.2

Bi-Cd-Pb-Sn.— (*Cont'd*)

t	ρ_t
76.4	91.9
77.4	93.65
78.5	95.2
86.2	102.2
88.0	102.85
96.5	105.5
98.5	106.5

Bi-Pb-Sn

Rose's metal (283)

Bi, 48.90; Pb, 27.54; Sn 23.55

129.8	92.25
122.5	91.7
117.5	91.3
109.8	90.8
104.1	90.25
97.2	90.1
95.2	89.8
93.5	88.15
93.0	86.75
92.6	85.75
91.0	76.15
85.0	72.9
78.2	72.3
71.7	72.0
64.7	71.4
61.1	71.1
50.2	70.25
42.8	69.5
38.0	69.1
33.7	68.3
31.1	68.2
28.0	68.0
22.7	67.1
16.7	66.7
7.4	65.4
0.0	64.4
10.0	65.6
20.0	66.9
35.9	68.8
42.7	69.8
48.4	70.4
59.0	70.5
69.2	72.6
85.7	75.06
89.9	76.1
93.5	77.9

Bi-Pb-Sn-Cd

Lipowitz' alloy (283)

124.1	98.6
111.0	97.6
108.7	97.25
93.8	96.85
88.0	96.6
87.2	96.4
83.5	96.4
75.9	96.0
71.7	95.9
69.0	95.25

Bi-Pb-Sn-Cd.— (*Cont'd*)

t	ρ_t
69.0	93.5
68.2	91.4
68.0	74.7
67.0	66.0
66.5	62.3
66.0	62.15
61.2	61.9
57.1	61.4
53.1	61.0
50.5	60.65
45.0	60.2
38.0	59.6
33.8	53.8
26.8	57.66
24.0	56.04
23.0	55.5
22.0	55.3
15.0	54.32
+13.1	54.2
− 4.0	51.9
− 4.0	51.9
0.0	52.5
+ 7.8	53.3
10.1	53.6
23.2	55.1
33.0	56.4
39.7	57.3
44.0	57.9
50.8	58.9
56.0	59.6
60.0	60.2
66.0	61.0
72.2	63.0
72.8	64.8
73.5	65.5

$CdCl_2$-Cd(6)

t	$0.001\rho_t$
0.0 % Cd	
580	532
$f^* = -77.5$	
$g^* = +12.5$	
700	457
2.11 % Cd	
580	537
$f^* = -81.7$	
$g^* = +13.9$	
700	459
4.51 % Cd	
580	545
$f^* = -85.0$	
$g^* = +13.9$	
700	463
7.38 % Cd	
580	558
$f^* = -95.0$	
$g^* = +16.7$	
700	468

$*\frac{\rho_t - \rho_{580}}{1000} = \frac{f}{100}(t - 580) + \frac{g}{10\,000}(t - 580)^2$; for a second set of mixtures, ρ's were 1 % to 2 % less than those here given.

Cd-Pb; *v.* Pb-Cd

Cu-Al; *v.* Al-Cu

Cu-Ni (23)

t	ρ_t
19 % Ni	
$t_m = 1187$	
1187	53.7
1200	53.8
1250	54.4
1300	55.5
1350	57.2
1400	59.2
1450	**62.6**
1500	66.5
1550	70.0
50.8 % Ni	
$t_m = 1326$	
1326	93.0
1350	93.6
$D = 2.33$	
1650	100.6
1450	**95.9**
65.3 % Ni	
$t_m = 1358$	
1358	136.7
1400	138.5
$D = 4.35$	
1600	147.2
1450	**140.6**
86.6 % Ni	
$t_m = 1419$	
1419	120.0
1450	**120.6**
$D = 2.20$	
1650	125.0

Cu-Pb (24)

0 % Pb	
1100	21.52
$D = 0.882$	
1500	25.05
1300	**23.29**
2 % Pb	
1100	24.00
$D = 1.103$	
1400	27.31
1300	**26.20**
2.95 % Pb	
1100	25.06
$D = 1.157$	
1400	28.53
1300	**27.37**
16.92 % Pb	
1100	42.13
$D = 0.948$	
1500	45.92
1300	**44.04**
35.98 % Pb	
1100	60.82
$D = 1.077$	
1400	64.05
1300	**62.98**
36.30 % Pb	
1200	64.29
$D = 0.990$	
1500	67.26
1300	**65.31**

Cu-Pb.— (*Cont'd*)

t	ρ_t
39.40 % Pb	
1300	**66.69**
$D = 0.885$	
1500	68.46
88.90 % Pb	
1300	**124.20**
1400	127.08
90.95 % Pb	
1200	121.25
1300	**124.08**
1400	126.09
98.0 % Pb	
700	113.2
$D = 4.21$	
1400	142.7
1300	**138.5**
100 % Pb	
700	111.8
$D = 4.60$	
1200	134.8

Cu-Sb (23)

2 % Sb	
$t_m = 1070°$	
1070	29.00
1100	29.24
1150	29.97
1200	30.18
1250	30.62
1300	31.12
$D = +1.035$	
1500	33.19
16.8 % Sb	
$t_m = 885$	
885	84.00
900	84.09
$D = +0.505$	
1300	86.11
1000	**84.59**
23.6 % Sb	
$t_m = 815$	
815	104.50
850	104.29
900	103.99
950	103.64
1000	**103.39**
1050	103.21
1100	103.19
$D = 0.000$	
1200	103.19
33.3 % Sb	
$t_m = 639$	
639	140.01
700	139.18
750	138.46
800	137.79
850	137.10
900	136.40
950	135.63
$D = -2.05$	
1200	130.50
1000	**134.60**

Cu-Sb.— (*Cont'd*)

t	ρ_t
40 % Sb	
$t_m = 682$	
682	152.20
700	151.70
750	150.3
800	148.97
850	147.90
900	146.90
950	146.14
1000	**145.38**
$D = -0.990$	
1200	143.40
50 % Sb	
$t_m = 655$	
655	147.00
700	146.64
750	146.26
800	145.90
850	145.71
900	145.64
950	145.63
1000	**145.68**
1050	145.82
1100	146.00
1150	146.39
1200	146.80
70 % Sb	
$t_m = 543$	
543	119.40
600	118.40
$D = +2.40$	
1200	132.78
1000	**127.98**
80 % Sb	
$t_m = 533$	
533	116.44
600	118.10
$D = +2.40$	
850	124.10
900	125.39
950	126.70
1000	**128.10**
1050	129.60
1100	131.16
1150	132.70
98.85 % Sb	
$t_m = 625$	
625	122.9
650	123.49
$D = 2.41$	
850	128.31
900	129.60
950	130.94
1000	**132.36**
1050	135.90

Cu-Sn (24)

0 % Sn	
1100	**21.52**
$D = 8.82$	
1500	25.05
2 % Sn	
1100	**25.51**
$D = 1.02$	
1400	28.57

Cu-Sn.— (*Cont'd*)

t	ρ_t
4.76 % Sn	
1100	**32.71**
$D = 0.92$	
1400	35.47
20.0 % Sn	
900	58.53
$D = 0.192$	
1300	59.30
1100	**58.92**
1400	59.47
1500	59.63
38.43 % Sn	
800	74.02
900	73.05
1000	72.50
1100	**72.22**
1200	72.08
1300	72.15
1400	72.32
1500	72.60
42.5 % Sn	
800	74.95
900	74.20
1000	73.75
1100	**73.40**
1200	73.40
1300	73.80
1400	73.95
60 % Sn	
700	67.40
$D = 1.033$	
1000	70.50
1100	**71.75**
1200	73.10
1300	74.50
1400	75.90
80 % Sn	
600	59.80
700	61.90
800	63.98
$D = 2.037$	
1400	76.20
1100	**70.08**
100 % Sn	
300	49.45
400	51.60
500	53.85
$D = 2.239$	
1500	76.24
1100	**67.20**

Cu-Zn (24)

0 % Zn	
1100	**21.52**
$D = 0.885$	
1300	23.29
0.9 % Zn	
1100	**22.03**
$D = 1.000$	
1300	24.03
3.5 % Zn	
1100	**23.13**
$D = 1.100$	
1300	25.33

Cu-Zn.—(*Cont'd*)

t	ρ_t
15.0 % Zn	
1100	**29.87**
1200	30.43
20 % Zn	
1000	**33.03**
D = 0.40	
1200	33.83
1100	**33.44**
39.61 % Zn	
900	43.90
1000	*42.36*
53.84 % Zn	
850	48.10
D = −2.32	
1000	*44.62*
60.7 % Zn	
850	48.59
900	47.35
1000	*45.53*
66.0 % Zn	
850	47.87
D = −2.35	
1000	*44.34*
85.0 % Zn	
700	44.04
D = −1.24	
900	41.56
100 % Zn	
700	35.65
D = +0.05	
900	35.75

Cu-Zn-Pb (204)

34.58 % Zn; 2.42 % Pb; tr. of Fe, Sn	
20	7
50	7.55
944	41.61
1000	41.20
1084	40.11

Fe-C (24)

0 % C	
1550	133.3
D = 4.8	
1650	138.1
0.22 % C	
1500	136.6
D = 4.2	
1650	142.9
1.19 % C	
1450	150.1
D = 2.8	
1650	155.7
3.80 % C	
1200	148.2
D = 2.2	
1600	157.0

Hg-K (187)

1.65 % K	
t_s = 62	
62	128.80
100	133.95
150	140.80

Hg-K.—(*Cont'd*)

t	ρ_t
1.65 % K	
t_s = 62	
200	147.80
250	155.18
300	162.75
350	170.60
3.52 % K	
t_m = 162	
162	165.76
200	170.18
250	176.38
300	183.95
350	192.18
6.56 % K	
t_m = 262	
262	197.80
300	203.90
350	213.45
400	223.40
450	233.0
8.56 % K	
t_s = 287	
287	199.90
300	202.25
350	211.95
400	221.50
9.62 % K	
t_s = 282	
282	208.5
350	222
400	232
11.92 % K	
t_s = 256	
256	232.60
300	237.00
350	242.0
21.34 % K	
t_s = 162	
162	240.25
200	241.5
D = 3.12	
350	246.18
39.45 % K	
t_s = 87	
87	130.20
100	132.80
150	142.50
200	153.75
250	163.18
300	173.60
350	184.05
79.35 % K	
t_s = 57	
57	37.10
100	41.30
D = 9.71	
350	65.58
100 % K	
t_s = 64	
64	12.98
100	15.3
D = 6.48	
200	21.78

Hg-Na

t	ρ_t
0.11 % Na (23)	
50	99.76
100	102.74
150	110.20
200	116.56
250	123.60
300	131.42
0.11 % Na (187)	
t_s = −43	
100	103.75
150	109.25
200	115.00
250	121.50
300	128.50
350	135.90
0.39 % Na	
t_s = −32	
50	100.30
100	105.95
150	111.65
200	117.50
250	123.90
300	130.90
350	138.60
0.95 % Na	
t_s = +56	
56	98.1
100	102.90
D = 10.74	
350	129.75
3.03 % Na	
t_s = 250	
250	110.70
D = 8.60	
400	123.60
4.85 % Na	
t_s = 352	
352	110.15
D = 4.90	
450	115.05
5.7 % Na	
t_s = 360	
360	122.0
400	123.8
450	126.2
7.44 % Na	
t_s = 320	
320	126.4
350	128.05
D = 5.70	
500	136.6
17.35 % Na	
t_s = 112	
112	122.9
200	127.0
D = 5.33	
350	135.0
32.0 % Na	
t_s = 47	
47	105.6
100	107.40
D = 3.47	
400	117.80

Hg-Na.—(*Cont'd*)

t	ρ_t
58.7 % Na	
t_s = 65	
65	59.4
100	51.6
D = 3.34	
400	61.62
100 % Na	
t_s = 98	
98	19.75
100	9.8
D = 3.78	
200	13.58

K-Hg; *v.* **Hg-K**

K-Na (197)

4.75 % K	
t_s = 42	
42	20.82
50	21.48
100	24.33
150	27.50
200	30.95
14.2 % K	
t_s = 17	
17	32.40
50	34.38
100	37.40
150	40.70
200	44.40
26.7 % K	
t_s = −12.5	
−12.5	35.65
+50	39.00
D = 5.76	
200	47.65
42.5 % K	
t_s = +6.5	
6.5	35.75
50	38.18
D = 5.55	
150	43.73
200	46.21
62.6 % K	
t_s = 30.0	
30.0	28.75
50	29.73
D = 4.98	
200	37.20
87.14 % K	
t_s = 71	
71	17.25
100	18.46
D = 4.19	
200	22.65
93.34 % K	
t_s = 82	
82	13.05
100	13.8
D = 4.22	
200	18.02

K-Rb; *v.* Table 2

K-Tl (23)

t	ρ_t
7.82 % Tl	
t_m = 110	
110	21.30
150	26.40
200	30.36
D = 10.0	
350	45.40

Na-Cd (23)

4.39 % Cd	
t_m = 122	
122	15.30
150	16.18
200	17.71
250	19.25
300	21.24
350	23.36

Na-Hg, Na-K; *v.* **Hg-Na, K-Na**

Na-Pb (23)

8.26 % Pb	
t_m = 185	
185	24.0
200	24.74
D = 4.78	
350	31.91

Na-Sb (23)

0.51 % Sb	
t_m = 104	
104	10.24
150	12.04
D = 4.03	
350	20.10

Na-Tl (23)

7.61 % Tl	
t_m = 93	
93	20.40
100	20.48
150	22.32
200	24.10
250	26.00
300	28.24
350	30.58

Ni-Cu; *v.* **Cu-Ni**

Pb-Bi (197)

0 % Bi	
t_s = 327	
327	94.6
400	**98.0**
D = 4.62	
1000	125.7
1.197 % Bi	
t_s = 327	
327	97.8
400	**97.8**
D = 4.60	
1000	125.4

Pb-Cd (197)

0 % Cd	
t_s = 327	
327	94.6
400	**98.0**

Pb-Cd.—(*Cont'd*)

t	ρ_t
0 % Cd	
D = 4.60	
800	116.4
1.44 % Cd	
t_s = 313	
313	93.2
400	**97.1**
D = 4.50	
800	115.1
2.9 % Cd	
t_s = 300	
300	92.0
400	**96.5**
D = 4.45	
800	114.3

Pb-Cu; *v.* **Cu-Pb**

Pb-K (23)

0.38 % K	
t_m = 319	
319	93.6
350	95.76
D = 6.98	
600	113.22

Pb-Na (23)

0.11 % Na	
t_m = 326	
326	95.64
350	96.90
D = 5.31	
650	112.84

Pb-Sb (197)

0 % Sb	
t_s = 327	
327	94.6
400	**98.0**
D = 4.62	
1000	125.7
0.76 % Sb	
t_s = 315	
315	94.1
400	**97.9**
D = 4.56	
1000	125.25
2.03 % Sb	
t_s = 300	
300	93.0
400	**97.6**
D = 4.57	
1000	125.00
18.39 % Sb	
t_s = 253	
253	96.9
400	**102.6**
D = 3.95	
1000	126.3

Pb-Sn (23)

t	ρ_t
0.76 % Sn	
t_m = 324	
324	94.10
350	95.21
400	97.38
450	99.55
500	101.80
550	104.10
600	106.42
650	108.75
96.76 % Sn	
t_m = 224	
224	48.66
250	49.13
300	50.48
350	51.69
400	52.91
450	54.20
500	55.50
550	56.80
600	58.13
650	59.42
98.35 % Sn	
t_m = 228	
228	48.38
250	46.90
300	50.00
350	51.14
400	52.30
450	53.45
500	54.68
550	56.00
600	57.50
650	59.08

(150); *cf.* (285)*

5 % Sn	
0	19.6
D = 8.40	
288	43.8
294	44.4
299	45.7
306	50.9
307	54.6
312	75.9
315	82.4
317	85.3
330	86.0
D = 4.08	
455	91.1
10 % Sn	
0	18.2
D = 8.82	
245	39.8
256	41.2
265	42.5
280	44.3
294	46.9
306	78.1
325	80.5
D = 3.51	
436	84.4

Pb-Sn.—(*Cont'd*)

t	ρ_t
20 % Sn	
0	17.1
D = 8.34	
175	31.7
180	32.3
180	34.6
180	36.4
195	37.7
207	39.6
211	40.0
230	42.0
248	46.5
260	53.2
269	59.0
274	64.5
293	73.3
D = 3.52	
455	79.0
30 % Sn	
0	15.3
D = 8.05	
174	29.3
178	29.5
183	33.0
184	35.6
186	39.8
195	40.7
208	42.4
225	45.9
232	47.6
248	54.5
253	57.7
256	62.0
261	65.0
273	67.2
289	67.5
D = 3.37	
455	73.1
40 % Sn	
0	14.6
D = 6.30	
135	23.1
140	24.0
156	25.1
164	25.8
175	27.1
178	27.5
179	30.2
179	41.7
181	42.7
188	43.9
199	46.5
212	49.2
218	52.5
225	54.0
234	58.7
236	60.5
242	61.6
247	61.9
D = 3.14	
470	68.9

Pb-Sn.—(*Cont'd*)

t	ρ_t
50 % Sn	
0	14.2
D = 6.45	
141	23.3
168	25.3
177	26.2
182	27.0
182	36.4
185	41.3
195	49.0
205	52.0
211	54.0
225	57.8
234	58.0
239	58.6
D = 2.74	
403	63.1
80 % Sn	
0	12.1
D = 6.39	
169	22.9
180	24.0
182	25.3
182	26.2
183	34.1
188	36.4
190	38.3
195	41.2
200	49.0
205	51.4
215	52.5
D = 2.82	
364	56.7
90 % Sn	
0	12.0
D = 5.35	
165	20.8
174	21.2
178	21.6
180	22.2
180	24.8
184	26.0
197	29.9
206	35.4
215	45.8
217	49.4
D = 2.77	
390	54.2
0.0 % Sn (197)	
t_s = 327	
327	94.6
400	**98.0**
D = 4.62	
1000	125.7
0.66 % Sn	
t_s = 326	
326	93.7
400	**97.1**
D = 4.52	
1000	124.2

Pb-Sn.—(*Cont'd*)

t	ρ_t
0.67 % Sn	
t_s = 325	
325	93.0
400	**96.4**
D = 4.52	
1000	123.5
1.83 % Sn	
t_s = 321	
321	92.5
400	**96.0**
D = 4.45	
1000	122.7
4.86 % Sn	
t_s = 308.8	
308.8	90.7
400	**94.6**
D = 4.23	
1000	120.0
11.51 % Sn	
t_s = 287.5	
287.5	82.3
300	82.8
D = 3.99	
1000	110.7
400	**86.8**
24.22 % Sn	
t_s = 263.8	
263.8	73.2
300	74.4
D = 3.37	
1000	98.0
400	**77.8**
40.08 % Sn	
t_s = 236.3	
236.3	65.8
300	67.5
D = 2.89	
1000	87.7
400	**70.3**
89.47 % Sn	
t_s = 207.5	
207.5	48.0
300	50.4
400	**52.8**
D = 2.93	
1000	70.4
100 % Sn	
t_s = 232	
232	47.6
300	49.1
400	**51.4**
500	54.0
D = 2.92	
1000	68.6

* Relative values; curves similar to those of data (150) here given, but discontinuity on heating occurs near 180° in all cases, and the upper linear portion begins at 200 to 230°C.

Pb-Zn (150)

t	ρ_t
2 % Zn	
0	18.8
D = 8.63	
313	45.8
315	50.2
315	63.8
317	72.8
319	77.3
320	80.7
322	84.0
327	87.0
357	89.1
380	91.8
429	94.1
480	96.4
510	97.6
5 % Zn	
0	18.5
D = 8.34	
283	42.1
315	60.2
315	79.2
316	84.7
333	86.7
354	88.6
371	90.6
394	93.1
419	94.9
438	95.8
462	96.4
488	97.4
521	98.5
10 % Zn	
0	18.7
D = 7.16	
289	39.4
310	41.6
315	56.3
315	73.4
330	75.0
352	76.4
368	77.7
393	79.6
410	80.8
415	85.5
432	86.1
441	86.6
470	88.0
545	91.4
589	92.6
20 % Zn	
22.0	20.0
60.0	22.2
D = 7.39	
294	39.5
315	41.9
315	53.1
336	70.4
354	72.0
372	72.8
382	74.3
399	75.5
415	76.2
415	83.8

Pb-Zn.—(*Cont'd*)

t	ρ_t
20 % Zn	
D = 7.39	
421	85.2
445	85.9
500	88.1
550	90.0
605	92.4
690	97.1
30 % Zn	
17.6	19.9
70	23.1
D = 7.75	
310	41.7
315	42.3
316	44.5
316	51.4
320	59.0
330	70.6
340	71.5
350	72.2
360	73.5
390	75.2
405	77.0
415	77.4
427	89.9
450	90.5
471	91.3
510	92.3
50 % Zn	
0	13.9
D = 6.27	
295	32.4
305	33.3
310	41.7
313	46.4
315	50.1
316	52.9
322	56.8
330	57.6
355	59.3
410	63.7
414	68.2
422	72.3
452	73
70 % Zn	
20	10.9
100	14.2
D = 4.50	
291	22.8
308	23.6
316	24.4
319	26.7
320	29.8
323	33.9
327	38.5
335	38.9
353	39.7
380	40.8
400	41.1
416	42.1
416	48.4

Pb-Zn.—(*Cont'd*)

t	ρ_t
70% Zn	
D = 4.50	
429	52.5
445	53.0
507	53.7
90% Zn	
0	6.1
D = 2.99	
308	15.3
316	15.6
318	17.7
320	20.0
325	20.4
351	20.9
375	22.0
400	23.0
410	23.7
414	25.4
416	30.8
416	35.4
430	36.4
450	36.4
468	36.4
498	36.4
0.00% Zn (197)	
t_s = 327	
327	94.6
D = 4.62	
1000	125.7
800	**116.4**
0.48% Zn	
t_s = 335	
335	93.2
D = 4.77	
1000	124.9
800	**115 5**
1.44% Zn	
t_s = 400	
400	94.8
D = 4.67	
1000	122.8
800	**113.5**
2.3% Zn	
t^* = 437	
437	95.6
D = 4.11	
800	**110.5**

Pb-Zn.—(*Cont'd*)

t	ρ_t
3.40% Zn	
t^* = 515	
515	97.5
D = 4.23	
800	**109.55**
6.44% Zn	
t^* = 587	
587	99.1
D = 4.19	
900	112.2
800	**108.0**
7.41% Zn	
t^* = 602	
602	97.0
D = 3.86	
900	108.5
800	**104.6**
11.52% Zn	
t^* = 647	
647	97.7
D = 3.83	
900	107.4
800	**103.5**
17.68% Zn	
t^* = 727	
727	90.2
D = 2.51	
900	94.55
800	**92.0**
20.38% Zn	
t^* = 783	
783	87.7
D = 2.48	
900	90.6
800	**88.1**
100% Zn	
t_s = 419	
419	35.30
D = 0.105	
800	**35.70**

*Temperature at which separation occurs.

Sb-Cu; *v.* **Cu-Sb**

Sn-Cu; *v.* **Cu-Sn**

Sn-K (23)

t	ρ_t
0.16% K	
t_m = 245	
245	49.02
250	49.1
300	50.09
350	51.08
400	52.58
450	54.18
500	56.00
550	57.90

Sn-Na (23)

0.14% Na	
t_m = 231	
231	47.61
250	48.18
D = 3.03	
500	55.75

Sn-Pb; *v.* **Pb-Sn**

Sn-Sb (23)

1.22% Sb	
t_m = 234	
234	48.16
250	46.10
300	49.88
350	51.16
400	52.40
450	53.69
500	54.95
550	56.28
600	57.62

Sn-Zn (23)

0.55% Zn	
t_m = 232	
232	47.58
250	48.02
D = 2.65	
650	58.61
0.95% Zn	
500	54.15
D = 2.30	
650	57.60

Zn-Cu; *v.* **Cu-Zn**

Zn-Pb; *v.* **Pb-Zn**

TABLE 4.—EFFECT OF HEAT TREATMENT UPON RESISTIVITY OF STEELS

Certain commercial steels are indicated by "Key" numbers; Chrome **1** to **8, 30, 31**; Martin Assailly **9, 10**; Holtzer crucible **11, 12, 14, 15**; Imphy crucible **13**; Allevard electrical **16**; Edgar Allen crucible **17**; Molybdenum **18, 19**; Tungsten **20** to **24, 32**; Whitworth mild **25, 26**; Manganese **27, 28**; Silicon **29**. Data for single temperatures have been placed in Table 2, *q.v.* Unit of $\rho = 10^{-6}$ ohm-cm; temperature = t, °C.

I. Effect of reheating; carbon steels (for analyses, *see* original papers); t = 25°C (49); *cf.* (48, 191)

C	0.04	0.30	0.35	0.41	0.57	0.76	0.945	1.05
t_Q	908°	908°	908°	908°	908°	903°	903°	903°
ρ_Q	11.10	16.04	17.63	18.46	21.41	30.95	36.82	40.07
t_{Dr}	ρ_{Dr}							
100	10.93	15.65	17.16	17.76	19.84	25.72	28.82	30.62
205	10.74	14.78	16.37	16.76	17.69	22.15	23.08	23.83
309	10.67	13.91	15.28	15.61	15.97	19.67	19.77	19.87
388	10.73	13.68	15.05	15.11	15.58	18.94	18.94	18.97
495	10.73	13.27	14.85	14.88	15.11	18.32	18.28	18.42
599	10.73	12.88	14.49	14.59	14.75	17.16	17.19	17.86
696	10.66	12.74	14.41	14.55	14.65	16.50	16.50	17.29
800	10.70	13.13	14.55	14.58	15.05	17.43	17.29	17.46

t = 20°C (48); *cf.* (49)				t = 20°C (88)		
C*	0.94	1.04	2.71	C†	1.29	1.29
t_Q	892°	892°	892°	t_{Tp}	800°	1150°
ρ_Q	35.95	41.92	52.59	ρ_{Tp}	29.68	45.35
t_{Dr}	ρ_{Dr}			t_A	ρ_A	
105	27.97	33.02	42.65	100	27.45	43.61
195	22.40	25.73	32.49	200	20.92	38.33
295	19.42	21.82	27.41	300	18.47	26.38
400	18.37	20.62	26.17	350	16.77	19.52
492	17.60	19.92	24.92	400	16.96	18.97
600	16.65	19.60	24.21	600	16.40	17.55
700	16.19	19.03	22.57	700	16.40	17.25
800	17.23	19.08	20.82	925	16.40	17.25

II. Variation with temperature of tempering and of quenching; carbon steels, 0.8% < C < 1.2%; $\rho_Q - \rho_{Q'} = 0.04(t_Q - 800)$C if 800° ≷ t_Q ≷ 1100°; $t_{Q'}$ = 800° (50, 166, 191).

t_{Tp}	710°	740°	810°	850°	950°	1000°	C
ρ_{Tp}/ρ_A	1.0	1.3	2.1	2.2		2.2	0.84%
ρ_{Tp}/ρ_A	1.0	1.3	1.6	2.1	3.0		1.13%

Alloy steels, composition 1/100 %

t = 15° (165, 166)					ρ for t_{Tp}		
Key¶	Cr	Si	Mn	C	0°§	750°	850°	1100°
1	250	27	23	50	19.5	19.5	29.2	40.9
2	280	27	21	82	21.5	28.0		66.7
3	240	36	21	107	24	31.2	36.0	72.0
t = 20° (218)					800°	900°	950°	1050°
4	882‡	25	0	10	50.82	49.20	52.71	52.71
5	1724	34	tr.	13	52.71	57.23	60.63	65.26
6	2742	42	tr.	8	57.45	57.45	57.94	59.50
7	1018	34	5	75	48.25	47.50	57.50	62.42
8	2934	22	0	31	66.30	66.43	68.31	67.50

t = 20° (218)					ρ for t_{Tp}			
Key‖	Mn	Si	S	C	0°§	750°	850°	1000°
9	36	1	0.9	11	13.30	14.31		14.36
10	47	tr.	2.2	17	11.11	13.28		13.13
11	12	8	3.4	30	14.26	13.49	15.60	16.07
12	14	11	2.5	37	15.17	19.40		19.65
13	14	9	2.2	56	16.83	20.54		23.60
14	14	8	1.3	88	16.84	28.72	35.79¶	
15	10	4	0.9	108	16.62	26.35	36.28¶	38.05
16	20	12	2.7	130	20.08	31.32		48.88
17	48	27	3 8	204	25.12	40.16	46.87	54.70
(218)	Mo**	Si	S	C	800°	900°	950°	1050°
18	119	18	6.5	72	39.34		39.91	42.33
19	253	16	6.3	77	39.01	39.00		

Key **20** to **32** follow next section—(Mo, Mn, Si, C) steels. S, 2.5; P, 1.6; As, 2.0; N, 0.4 ($\frac{1}{100}$ %); t = 16 to 20°C; t_{T_D} = 550°C after t_Q = 800°C (**268, 269**)

Mo	Mn	Si	C	ρ_{Ac}‡‡	ρ_A	ρ_{T_D}	ρ_{Q800}††	ρ_{Q1200}††	ρ_R
103	22	5	20		13.48	14.22	16.00		14.18
105	23	9	45		14.77	16.86	21.00		17.40
102	27	12	87	17.46	18.55	20.25	36.3		21.00
110	25	12	122	18.65	19.54	21.15	39.53	45.31	23.10
218	22	6	25		13.55	17.93	16.5	18.96	18.66
218	27	8	44		14.97	19.47	20.1	24.82	20.66
219	26	8	88	15.85	16.13	20.10	33.44		22.90
211	24	7	121	17.76	18.47	20.80	38.52	48.66	24.80
254	21	12	136		20.13	22.40	41.5		31.30
411	24	4	19		14.95	19.12	16.82	23.66	20.22
401	29	4	49		14.89	19.52	19.54	34.04	24.60
400	23	5	87	15.15	15.53	19.88	26.95	36.42	25.70
402	23	4	106	16.18	16.92	19.78	36.03		27.10
801	22	5	14	23.48	23.70	25.25	25.23	32.73	25.83
817	27	6	36		15.32	18.79	17.2	34.03	19.00
811	25	8	45		14.38	19.06	17.5	37.38	28.00
785	23	4	78	15.28	15.38	19.92	22.07	46.07	27.40
792	23	8	113	16.85	16.13	19.50	36.2	55.57	22.60

For Fe-Mo-Si-S-C, *v.* Key **18, 19.**

	t = 15° (**165, 166**)				ρ for t_{T_D}			
Key‖	W	Mn	Si	C	0°§	750°	850°	1100°
20	270	44	30	76	18.5	27.8	31.4	35.2
21	270	38	32	111	20.0	26	28	44
22	290	40	20	55	18	21.6		32.4
23	500	30	2	60	21	21	31.5	37.8
	t = 20° (**218**)				800°	900°	950°	
24	1354	0	13	6	18.48	19.05	21.07	

III. Effect of forging and hardening in oil (**128**); t = 0°C

Key‖	C	Mn	Si	Cr	W	P	ρ_F	ρ_A	ρ_H
25	32	44	4			4		14.46	13.90
26	89	16	8			2		15.59	16.95
27	67	473	61			8	53.68	39.28	55.56
28	130	874	9			7	69.93	63.16	70.66
29	68	69	344			13	61.63	61.85	61.95
30	53	39	22	62		4	20.16	19.42	27.08
31	69	3	13	120		4	17.91	18.49	30.35
32	136	4	4		465	5	22.49	22.50	22.74

* For C < 0.94, data from (**48**) agree well with those given above for (**49**).

† Contains also: 0.07Mn, 0.15Si, 0.006P, tr. S.

‡ In this case, S = 0.11 %, P = 0.11 %; in all other specimens of (**218**) they are less.

§ t_{T_D} = 0 indicates value before tempering.

‖ Key indicates type of steel: **1** to **8, 30, 31** = Chrome; **9, 10** = Martin Assailly; **11, 12, 14, 15** = Holtzer crucible; **13** = Imphy crucible; **16** = Allevard Electrical; **17** = Edgar Allen crucible; **18, 19** = Molybdenum; **20** to **24, 32** = Tungsten; **25, 26** = Whitworth mild; **27, 28** = Manganese; **29** = Silicon.

¶ t_{T_D} = 900°.

** For Fe-Mo-Mn-Si-C, *v.* below.

†† $\rho_{Q800}[\rho_{Q1200}] = \rho_Q$ when t_Q = 800° [1200°].

‡‡ Carbide annealed. Drastic annealing for carbide analysis, kept at 950°C for 10 hr and cooled over 55 hr.

TABLE 5.—ADDITIONAL REFERENCES

The papers here listed cannot be readily abstracted. Except for the named alloys, the papers are listed solely with reference to the individual metals contained in the alloys studied.

Ag (**36, 57, 94, 95, 96, 156, 181, 183, 185, 231, 251**)
Al (**8, 36, 37, 94, 205, 214, 266, 296**)
As (**79, 228**)
Au (**94, 95, 96, 100, 156, 181, 183, 185, 231, 251**)
Bi (**7, 94, 96, 168, 247**)
C (**94, 115**)
Cd (**251, 257**)
Co (**94, 227**)
Cr (**94, 120**)
Cu (**8, 39, 43, 59, 79, 94, 96, 99, 100, 143, 145, 156, 185, 214, 227, 228, 231, 251, 257, 286**)
Fe (**8, 25, 26, 70, 94, 100, 108, 114, 115, 116, 214, 274, 278, 302**); *v. also* Mn-steel, Ni-steel, Steel
Hg (**22, 197**); *v. also* Amalgams
Ir (**94, 185**)
K (**22, 197**)
Mg (**36, 205**)
Mn (**94, 100**)
Na (**22, 197**)
Ni (**8, 44, 59, 77, 94, 120, 145, 156, 214, 251, 274, 302**)
P (**228**)
Pb (**7, 22, 94, 100, 168, 197, 231, 247**)
Pd (**94, 96, 149**)
Pt (**57, 94, 96, 185**)
Rh (**94**)
Sb (**94, 96, 99, 143**)
Si (**116**)
Sn (**7, 39, 94, 96, 156, 231, 247**)
Tl (**100**)
W (**94**)
Zn (**22, 39, 94, 96, 157, 197, 247, 251, 266, 286**)
Amalgams (**18, 60, 89, 92, 253, 292**)
Brass (**204, 256**)
Chromel (**32**)
Comet (**32**)
Constantan (**17, 272**)
German silver (**214**)
Manganin (**2, 17, 32, 171, 196, 233, 234, 255, 289, 291**)
Mn-steel (**164**)
Monel (**207**)
Nichrome (**259**)
Ni-steel (**42, 106, 107**)
Steel (**5, 11, 15, 16, 28, 29, 42, 53, 78, 106, 107, 109, 115, 163, 164, 206, 213, 248, 256, 274, 278**)
Therlo (**32**)
Low melting point alloys (**56**)
Telegraph wire (**290**)
Resistance at low temperatures (**62, 63**)
Temperature coefficients (**261**)
Effect of stress (**32, 256, 271, 272**)
Theoretical (**41, 61, 97, 98, 101, 157, 177, 213, 243, 244, 257, 263, 275, 294**)
Miscellaneous (**62, 63, 74, 181, 188, 201, 258, 270**)
Bibliographies (**35, 94, 239**)

LITERATURE

(For a key to the periodicals see end of volume)

(**1**) Addicks, *80*, **36**: 18; 06. (**2**) Ahler, Haas and Angerstein, *101*, **12**: 250; 91. (**3**) American Nickel Corpn., Clearfield, Pa., *O.* (**4**) d'Amico, *139*, **10**: 289; 12. (**5**) Andrew, Rippon, Miller and Wragg, *140*, **101**: 527; 20. (**6**) Aten, *7*, **73**: 578; 10. (**7**) van Aubel, *149*, **19**: 105; 88. *51*, **4**: 72; 95. (**8**) van Aubel and Paillot, *51*, **4**: 522; 95. (**9**) Barrett, *5*, **69**: 480; 02.

(**10**) Barratt, *67*, **26**: 347; 14. (**11**) Barrett and Brown, *133*, **1899**: 856. (**12**) Barrett, Brown and Hadfield, *434*, **7**: 67; 02. (**13**) Barrett, Brown and Hadfield, *46*, **31**: 674; 02. (**14**) Barrett, Brown and Hadfield, *434*, **8**: 109; 04. (**15**) Barus, *8*, **7**: 383; 79. (**16**) Barus, *2*, **29**: 516; 09. (**17**) Bash, *80*, **64**: 239, 261; 21. (**18**) Battelli, *170*, **4**: 206; 87. (**19**) Beckman, *Thesis*, Upsala, 1911.

(**20**) Benedicks, *7*, **40**: 545; 02. (**21**) Benedicks, *Recherches physiques et physico-chimiques sur l'acier au carbone.* Paris, Dunod, 1904. (**22**) Bornemann and Müller, *192*, **7**: 396; 10. (**23**) Bornemann and Rauschenplat, *192*, **9**: 473, 505; 12. (**24**) Bornemann and Wagenmann, *139*, **11**: 289; 14. (**25**) Boudouard, *140*, **63**: 299; 03. (**26**) Boudouard, *420*, **105**: 449; 03. (**27**) Boudouard, *34*, **153**: 1475; 11. (**28**) Boudouard, *74*, **9**: 294; 12. (**29**) Brant, *2*, **29**: 485; 09.

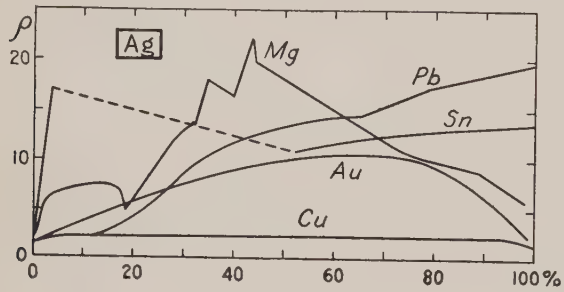
(**30**) Breckenridge, *78*, **17**: 367; 10. (**31**) Bridgman, *65*, **47**: 319, 345; 11. (**32**) Bridgman, *65*, **56**: 59; 21. **57**: 41; 22. (**33**) Brockbank, *10*, **3**: 261; 12. (**34**) Broniewski, *34*, **149**: 853; 09. (**35**) Broniewski, *74*, **8**: 320; 11. (**36**) Broniewski, *34*, **150**: 1754; 10. **152**: 85; 11. (**37, 38**) Broniewski, *6*, **25**: 5; 12. (**39**) Broniewski, *74*, **12**: 961; 15.

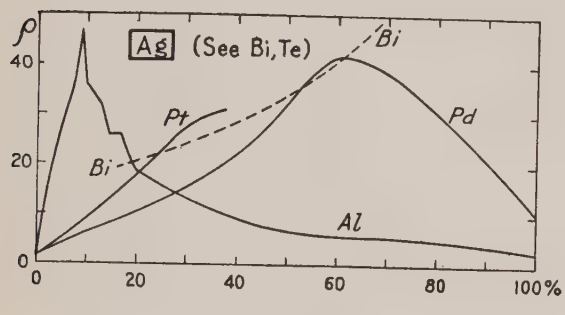
(**40**) Broker and Co., *O.* (**41**) Brooks, *63*, **11**: 471; 10. (**42**) National Bur. Standards, *365*, No. **58**; 16. (**43**) *Idem.*, *365*, No. **73**; 22. (**44**) *Idem.*, *365*, No. **100**; 24. (**45**) Burgess and Aston, *33*, **8**: 79, 131; 10. (**46**) Burgess and Aston, *78*, **20**: 205; 11. (**47**) Calvo, *Ion*, **2**: 408; 10. (**48**) Campbell, *140*, **92**: 164; 15. (**49**) Campbell, *140*, **94**: 268; 16.

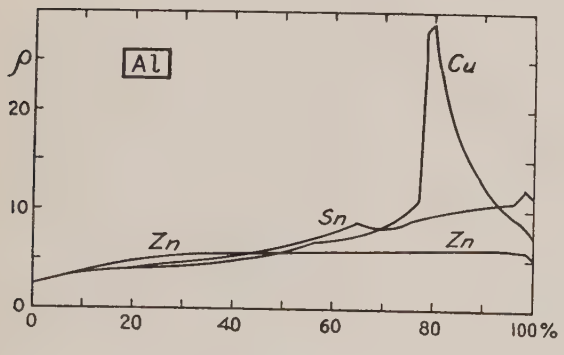
(**50**) Campbell, *83*, **15**: 138; 20. (**51**) Campbell and Whitney, *140*, **110**: 291; 24. (**52**) Capp, *115*, **77**: 274; 04. (**53**) Carpenter, Hadfield and Longmuir, *115*, **80**: 708, 745, 779, 822; 05. (**54**) Carpenter, Hadfield and Longmuir, *403*, **1905**: 857. (**55**) Caswell, *2*, **12**: 226; 18. (**56**) Cattaneo, *23*, **27 II**: 419; 91. (**57**) Chevallier, *34*, **130**: 120, 1612; 00. (**58**) Chevallier, *51*, **1**: 157; 02. (**59**) Chevenard, *34*, **181**: 28; 25.

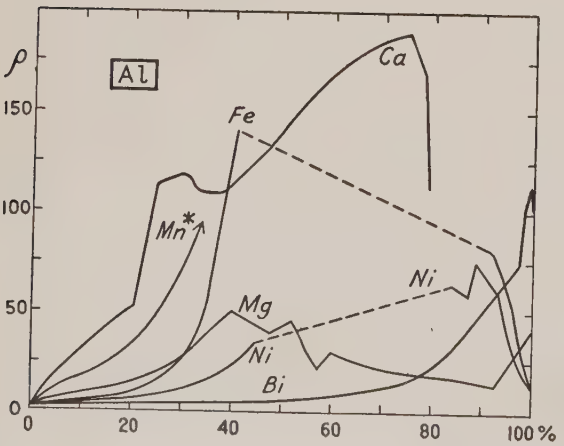
(**60**) Crace-Calvert and Johnson, *62*, **149**: 831; 60. (**61**) Crommelin, *200*, **19**: 38; 22. (**62**) Dewar and Fleming, *3*, **34**: 326; 92. (**63**) Dewar and Fleming, *3*, **36**: 271; 93. (**64**) Dow Chemical Co., Midland, Mich., *O.* (**65**) Driver-Harris Co, Harrison, N. J., *O.* (**66**) Drysdale, *121*, **59**: 989; 07. (**67**) Drysdale, *121*, **77**: 629; 16. (**68**) Dupuy, *34*, **172**: 1660; 21. (**69**) Durıron Co., Dayton, O., *O.*

Resistivity (ρ) of binary alloys. (For other and more accurate data, *see* Table 2.) The symbol of the metal common to the alloys of a chart is enclosed in a square, and the abscissae = Wt. % of the other metal. Unit of $\rho = 10^{-6}$ ohm-cm.

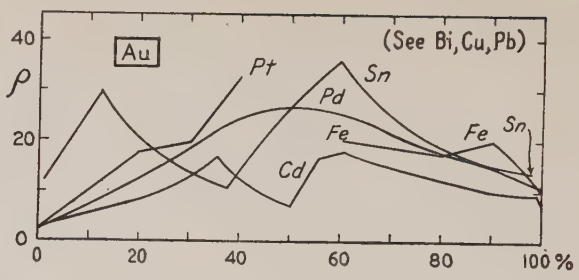


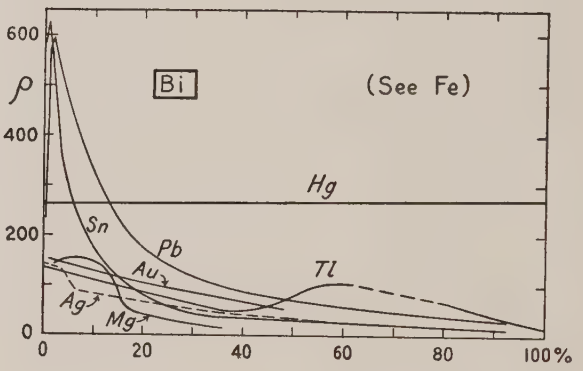


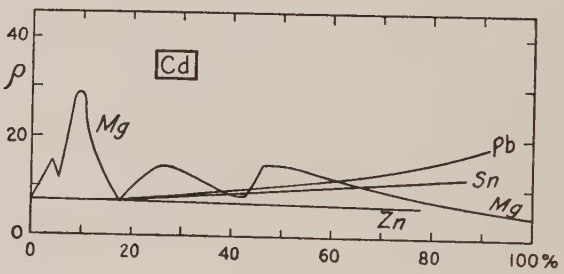


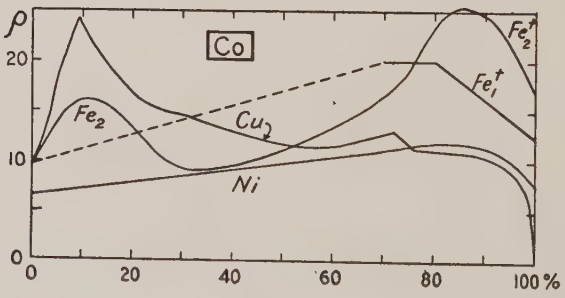


* For Al-Mn: At 40.4 % Mn, $\rho = 500$; at 46.9 % Mn, $\rho = 2000$.

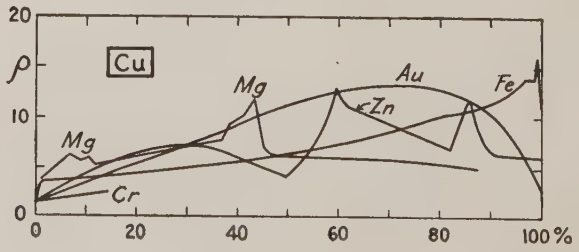


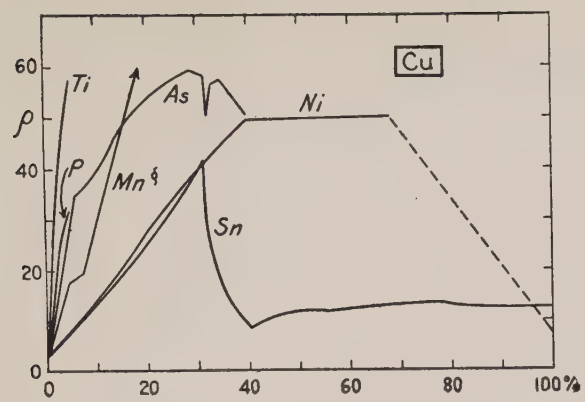




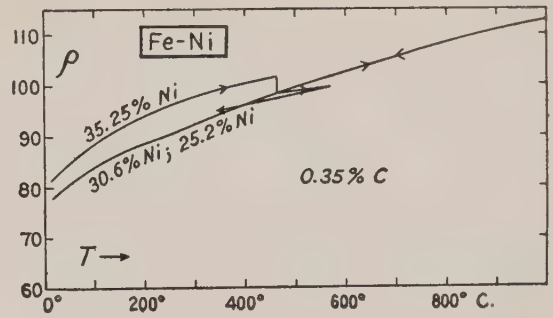


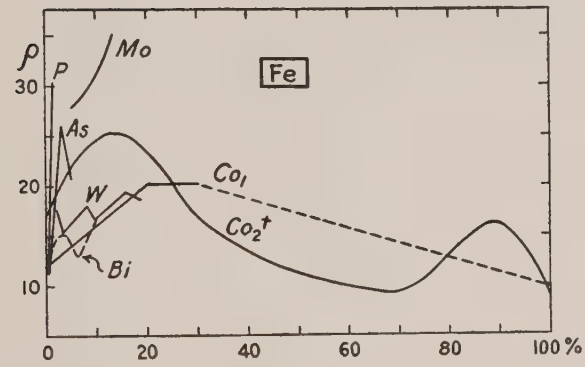
† For (Co, Fe_1) and (Fe, Co_1) the materials were pure, for (Co, Fe_2) and (Fe, Co_2) they were not; *see* Table 2, Fe-Co [120] and Fe-Co-x [121].



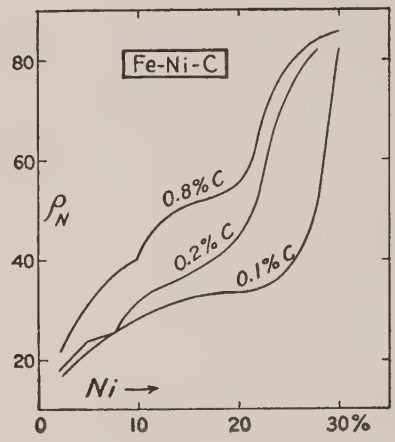


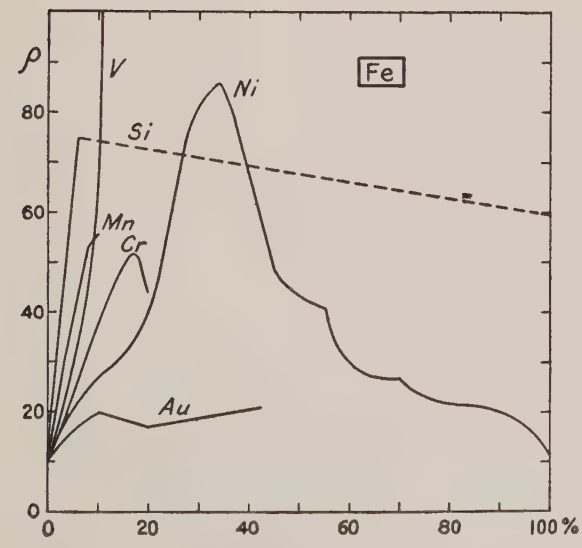
§ For Cu-Mn: At 40% Mn, $\rho = 133$; at 60% Mn, $\rho = 164$.

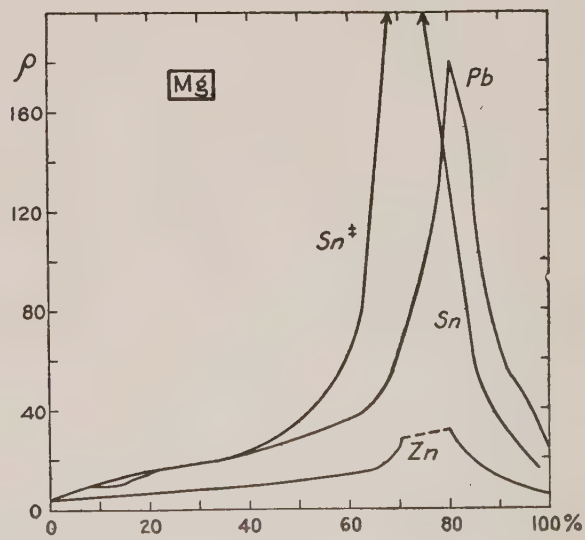




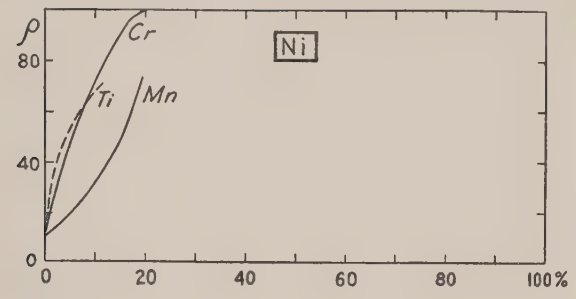
† For (Co, Fe_1) and (Fe, Co_1) the materials were pure, for (Co, Fe_2) and (Fe, Co_2) they were not; *see* Table 2, Fe-Co [120] and Fe-Co-x [121].

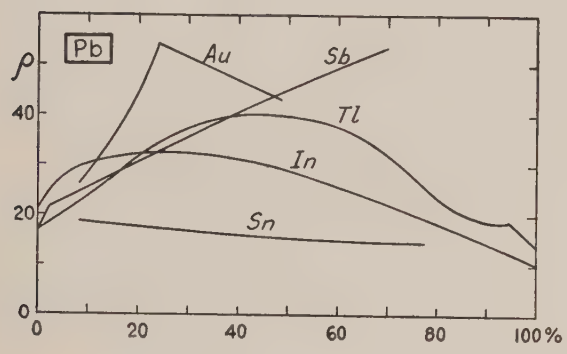


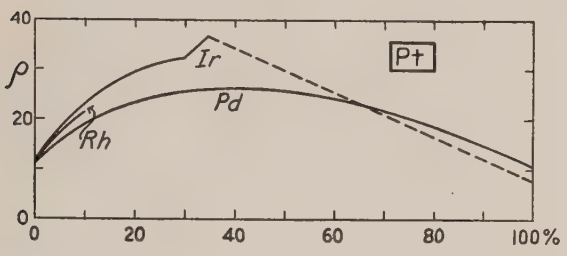


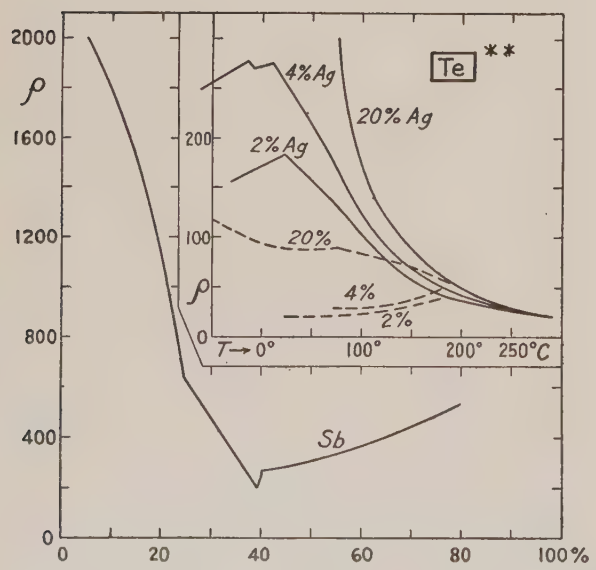


‡ For Mg-Sn: At 71% Sn, $\rho_{25} = 1100$.

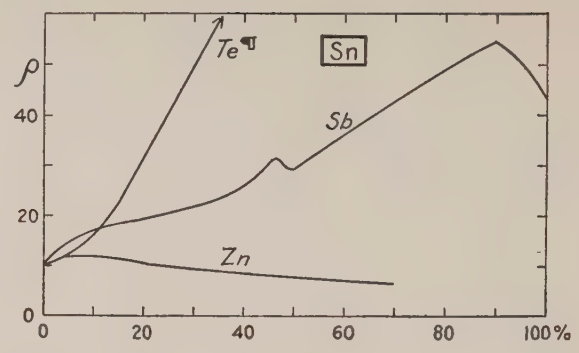






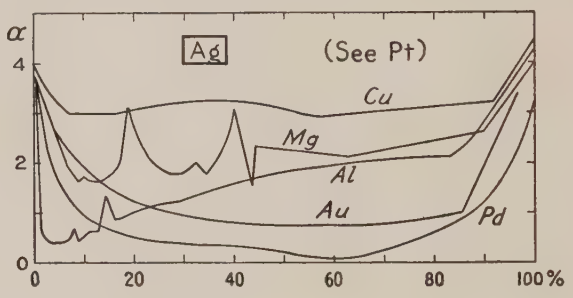


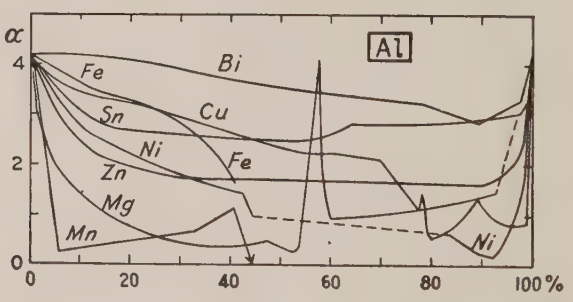
** For Te-Ag, continuous lines correspond to ρ_A, broken to ρ_f (cooled rapidly from melting point).

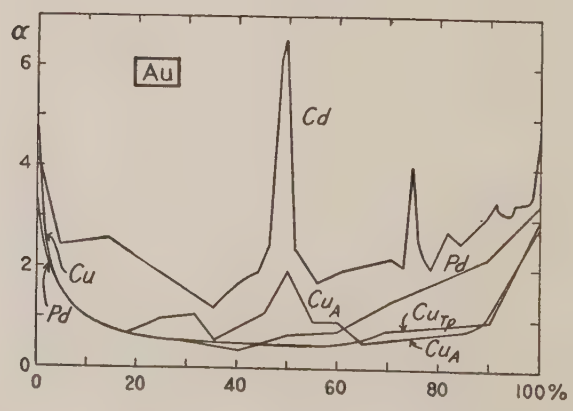


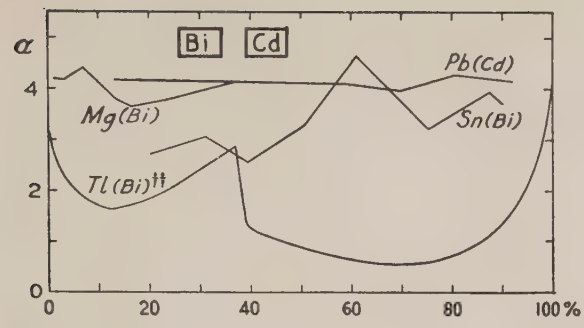
¶ For Sn-Te: At 90 % Te, ρ = 2780.

Temperature coefficient (α) of resistivity of binary alloys. (For other and more accurate data, *see* Table 2.) The symbol of metal common to the alloys of a chart is enclosed in a square, and the abscissae = Wt. % of the other metal. Unit of α = 0.1 % per 1°C.

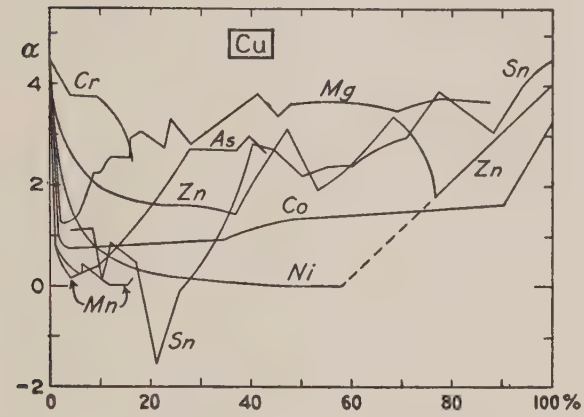


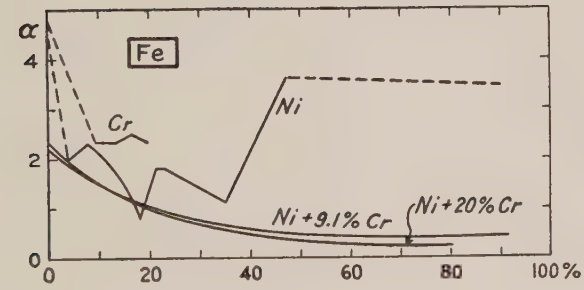


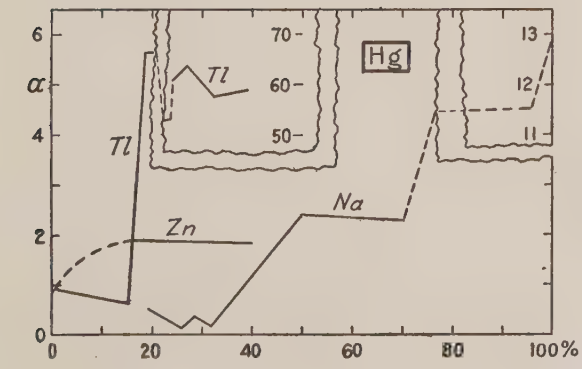


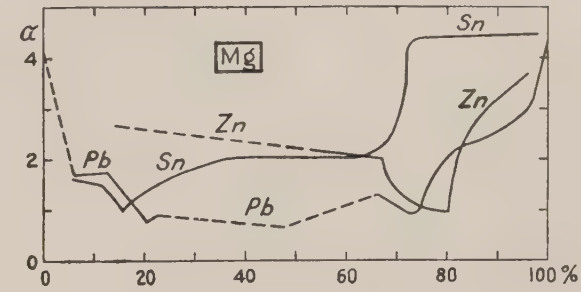


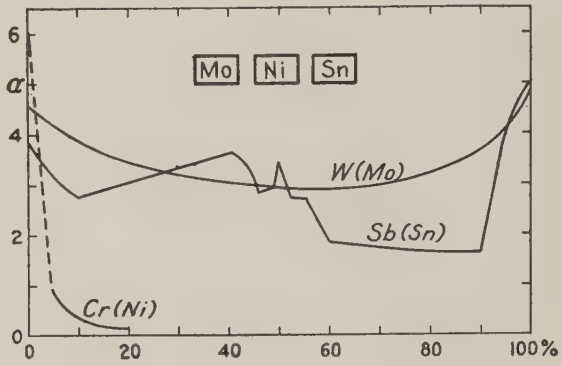
†† Curve for Tl(Bi) is for α_0 at 0°C, *cf.* Table 2, Bi-Tl.

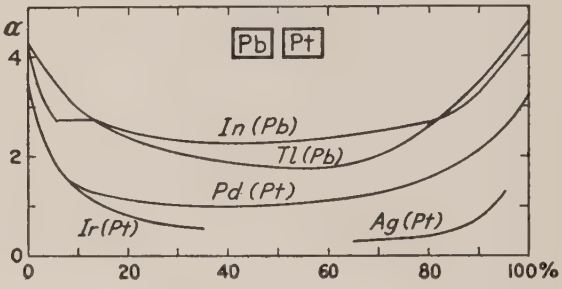












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(80) Geibel, *93*, **69**: 38; 10. (81) Geibel, *93*, **70**: 240; 11. (82) Geiss and van Liempt, *93*, **128**: 355; 23. (83) Geross, *22*, **2 II**: 344; 86. (84) Goerens, *417*, **3**: 320; 11. (85) Goerens, *74*, **10**: 608; 13. (86) Gray, *552*, **No. 4**; 12. (87) Greaves, *47*, **7**: 218; 12. (88) Grenet, *74*, **1**: 353; 04. (89) Gressman, *2*, **9**: 20; 99.

(90) Griffiths, *62*, **184**: 361; 94. (91) Griffiths, *115*, **123**: 475; 27. (92) Grimaldi, *170*, **4**: 46; 87. (93) Grüneisen, *8*, **3**: 43; 00. (94) Guertler, *93*, **51**: 397; 06. (95) Guertler, *9*, **13**: 441; 07. (96) Guertler, *200*, **5**: 17; 08. (97) Guertler, *63*, **9**: 404; 08. (98) Guertler, *63*, **11**: 476; 10. (99) Guertler, *47*, **6**: 135; 11.

(100) Guertler, *9*, **18**: 601; 12. (101) Guertler, *95*, **11**: 41; 19. (102) Guertler and Schulze, *7*, **104**: 90; 23. (103) Guertler and Schulze, *7*, **104**: 269; 23. (104) Guertler and Schulze, *7*, **106**: 1; 23. (105) Guillaume, *34*, **125**: 235; 97. (106) Guillaume, *51*, **7**: 262; 98. (107) Guillaume, *149*, **5**: 255, 305; 98. (108) Guillet, *140*, **90**: 66; 14. (109) Guillet, *74*, **20**: 656; 23.

(110) Guillet, *34*, **177**: 953; 23. *126*, **3**: 641; 23. (111) Guillet and Ballay, *34*, **172**: 1576; 21. (112) Guillet and Ballay, *34*, **176**: 1800; 23. (113) Guillet and Ballay, *Proc. verbal l'assoc. Fr. Belge pour l'essai des mat.*, **16**: 6; 23. (114) Gumlich, *101*, **40**: 334; 19. (115) Gumlich and Goerens, *83*, **8**: 98; 12. (116) Gumlich and Goerens, *77*, **39**: 765; 19. (117) Haas, *101*, **16**: 272; 95. *8*, **52**: 673; 94. (118) Hadfield, *140*, **1892 II**: 49. (119) Haken, *8*, **32**: 291; 10.

(120) Hart, *80*, **64**: 554; 21. (121) Herold, *93*, **112**: 131; 20. (122) Hine, *1*, **39**: 882; 17. (123) Honda, *159*, **7**: 59; 18. (124) Honda, *159*, **8**: 51; 19. (125) Honda and Matsushita, *159*, **8**: 89; 19. (126) Honda and Ogura, *159*, **3**: 113; 14. (127) Honda and Simidu, *159*, **6**: 219; 17. (128) Hopkinson, *62*, **176**: 455; 86. (129) Hopkinson, *5*, **47**: 138; 90.

(130) Hoskins Manufacturing Co., Detroit, Mich., *O.* (131) Hunter and Bacon, *78*, **36**: 323; 20. (132) Hunter and Bacon, *78*, **37**: 513; 20. (133) Hunter and Jones, *78*, **42**: 162; 23. (134) Hunter and Jones, *66*, **24**: 401; 24. (135) Hunter and Sebast, *40*, **11**: 115; 17. (136) Hunter, Sebast and Jones, *80*, **68**: 750; 23. (137) Ingersoll, *2*, **16**: 126; 20. (138) International Nickel Co., New York City, *O.* (139) Jaeger and Diesselhorst, *89*, **3**: 269; 00.

(140) Zhemchuzhnui, *74E*, **17**: 142; 20. (141) Jolley, in Cheneveau, *3*, **20**: 357; 10. (142) Kalmus and Harper, *45*, **7**: 6; 15. (143) Kamensky, *3*, **17**: 270; 84. (144) Kaye and Laby, *Tables of physical and chemical constants.* London, Longmans, 1918. (145) Kimura and Isawa, *338*, **No. 171**; 26. (146) Kimura and Namikawa, *338*, **No. 132**; 23. (147) Kimura and Sakamaki, *338*, **No. 114**; 22. (148) Klein, *101*, **45**: 300; 24. (149) Knott, *174*, **33**: 171; 88.

(150) Konno, *159*, **10**: 57; 21. (151) Konstantinov and Smirnov, *53*, **43**: 1201; 11. *169*, **15**: 151; 11. (152) Kurnakov and Nikitinski, *53*, **46**: 360; 14. (153) Kurnakov, Pushin and Senkowskii, *93*, **68**: 123; 10. (154) Kurnakov, Zhemchuzhnui and Zasedatelev, *53*, **47**: 871; 15. *169*, **22**: 497; 15. (155) Kurnakov and Zhemchuzhnui, *93*, **54**: 149; 07. (156) Kurnakov and Zhemchuzhnui, *93*, **60**: 1; 08. (157) Kurnakov and Zhemchuzhnui, *200*, **5**: 374; 08. (158) Kurnakov and Zhemchuzhnui, *93*, **64**: 149; 09. (158.1) *B3.* (159) Larsen, *8*, **1**: 123; 00.

(160) Law, *Alloys and their industrial applications.* London, Griffin, 1909. (161) LeChatelier, *34*, **110**: 283; 90. (162) LeChatelier, *34*, **111**: 454; 90. (163) LeChatelier, *34*, **112**: 40; 91. (164) LeChatelier, *34*, **119**: 272; 94. (165) LeChatelier, *34*, **126**: 1709, 1782; 98. (166) LeChatelier, *Contribution à l'étude des alliages*, **1896–1900**: 416. (167) Ledoux, *34*, **155**: 35, 1249; 12. (168) Leduc, *51*, **3**: 362; 84. (169) Lees, *62*, **208**: 381; 08.

(170) Liedgens, *77*, **32**: 2109; 12. (171) Lindeck, *243*, **28**: 229; 08. (172) Lodge, *3*, **8**: 554; 79. (173) MacGregor and Knott, *174*, **29**: 599; 80. (174) Mahler, *74*, **1905**: 345. (175) Major, *78*, **37**: 457; 21. (176) Mathews, *140*, **61**: 182; 02. (177) Mathews, *Metallographist*, **6**: 327; 03. (178) Matsushita, *159*, **8**: 79; 19. (179) Matsushita, *159*, **9**: 243; 20.

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(200) Neumann, *77*, **39**: 665; 19. (201) Niccolai, *22*, **16 II**: 185; 07. (202) Norsa, *34*, **155**: 348; 12. (203) Northrup, *78*, **20**: 185; 11. (204) Northrup, *33*, **12**: 161; 14. (205) Northrup, *33*, **15**: 193; 16. (206) Nusbaum and Chenet, *31A*, **17**: 65; 21. (207) Oakley, *440*, **6**: 61; 14. (208) Osmond, *74*, **3**: 551; 06. (209) Paglianti, *192*, **9**: 217; 12.

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(230) Rivière, *Diplomes d'études supérieures*, Paris, 1912: **No. 113**. (231) Roberts, *3*, **8**: 57, 551; 79. (232) Rodgers, *2*, **8**: 259; 16. (233) Rosa, *31A*, **5**: 413; 09. (234) Rosa, *107*, **75**: 941; 20. (235) Rudolfi, *63*, **9**: 198, 607; 08. (236) Ruer and Fick, *139*, **11**: 39; 13. (237) Ruer and Kaneko, *139*, **10**: 257; 13. (238) Ruer and Schütz, *192*, **7**: 415; 10. (239) Sack, *93*, **35**: 249; 03.

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(250) Sebast and Gray, *78*, **29**: 569; 16. (251) Sedström, *8*, **59**: 134; 19. (252) Simidu, *159*, **6**: 111; 17. (253) Skaupy, *7*, **58**: 560; 07. (254) Smirnov and Kurnakov, *93*, **72**: 31; 11. *169*, **14**: 623; 10. (255) Smith, *3*, **16**: 450; 08. (256) Smith, *2*, **28**: 107, 429; 09. (257) Smith, *33*, **25**: 1178; 21. (258) Smith, *143*, **192**: 69, 157; 21. (259) Somerville, *2*, **30**: 268, 532; 10.

(260) Somerville, *2*, **31**: 275; 10. (261) Somerville, *2*, **33**: 77; 11. (262) Stäblein, *96*, **20**: 209; 23. (263) Steinmetz, *78*, **11**: 81; 07. (264) Stepanov, *93*, **60**: 209; 08. (265) Stepanov, *93*, **78**: 1; 12. *53*, **44**: 910; 12. (266) Sturm, *Diss.*, Rostock, 1904. *427*, **29**: 143; 05. (267) Swinden, *140*, **80**: 223; 09. (268) Swinden, *417*, **3**: 66; 11. (269) Swinden, *417*, **5**: 100; 13.

(270) Swoboda, *107*, **77**: 944; 21. (271) von Szily, *51*, **8**: 329; 99. (272) von Szily, *34*, **128**: 927; 99. (273) Taylor, *133*, **1881**: 431. (274) Tomlinson, *5*, **56**: 103; 94. (275) Thomson, *47*, **14**: 3; 15. (276) Thompson, *46*, **54**: 222; 16. (277) Thompson and Miller, *1*, **28**: 1115; 06. (278) Thompson and Whitehead, *5*, **102**: 587; 23. (279) Urazov, *169*, **14**: 675; 10. *93*, **73**: 31; 12.

(280) Vanstone, *4*, **105**: 2617; 14. (281) Voigt, *93*, **120**: 309; 21. (282) Weber, *8*, **23**: 447; 84. (283) Weber, *8*, **27**: 145; 86. (284) Weber, *8*, **31**: 243; 87. (285) Weber, *8*, **34**: 576; 88. (286) Weber, *8*, **68**: 705; 99. (287) Wedding, *101*, **9**: 172; 88. (288) Wedding, Various papers in *Verh. Vereins zur Beförderung des Gewerbefleisses*, 1892–1902. (289) Wiechert, *8*, **52**: 67; 94.

(290) Weiller, *101*, **3**: 83, 157; 82. (291) Williams, *3*, **13**: 635; 07. (292) Williams, *3*, **50**: 589; 25. (293) Willows, *3*, **48**: 433; 99. (294) Willows, *3*, **12**: 604; 06. *63*, **8**: 173; 07. (295) Wilson, *46*, **31**: 321; 02. (296) Wilson, *133*, **1903**: 777. *121*, **51**: 898; 03. (297) Wilson, *121*, **67**: 907; 11. (298) Yensen, *86*, **No. 77**; 15. (299) Yensen, *86*, **No. 83**; 15.

(300) Yensen, *119*, **34**: 2455; 15. (301) Yensen, *129*, **39**: 791; 20. (302) Yensen, *107*, **75**: 774; 20. (303) Yensen, *45*, **16**: 366; 24. (304, 305) Yensen, *129*, **43**: 145; 24. (306) Yensen and Gatward, *86*, **No. 95**; 17. (307) Tanabe, *47*, **32**: 415; 24.

ELECTROELASTIC AND PYROELECTRIC PHENOMENA[1]

W. G. Cady

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Pyroelectricity.
Piezo and pyro effects at room temperature.
Tourmaline.
Quartz.
Rochelle salt ($KNaC_4H_4O_6.4H_2O$).
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Matières

Électrostriction.
Piézoélectricité.
Pyroélectricité.
Piézo-effets et pyro-effets à la température de la chambre.
Tourmaline.
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Electrostriction.—In general, when an isotropic dielectric is subjected to an electrostatic field E, its volume and form are changed. This phenomenon is known as *electrostriction*. The same kinds of effect occur in anisotropic dielectrics, but in them these effects are in many cases obscured by the far larger electrocrystallic ones described as piezoelectric (*see* p. 208). In electrostrictive effects, the tensions tending to stretch any element of the dielectric are proportional to E^2 and to $d\epsilon/dx$, where ϵ = dielectric constant and x is the amount of stretching in the direction considered. In general, $d\epsilon/dx$ depends upon the inclination of x to E; it may be either positive or negative, depending upon the nature of the dielectric (**2**). There are similar forces tending to move the dielectric bodily in such a way as to increase the integral value of ϵE^2, and if the dielectric is solid and if the field is produced by the charging of electrodes supported by it, then it will be subjected to the pressure arising from the mutual attraction of the electrodes. Deformations resulting from these two types of forces should not be classed as electrostrictive, although one or the other enters into many measurements of electrostriction.

Electrostrictive effects are generally derived from observations of the change in dimension of a condenser of which the dielectric is the substance to be studied (**2, 14, 20, 50, 57, 63, 74, 75, 82, 96, 97, 127**). If l is the dimension considered, Δl is the increase in l under action of the electric field, and if μ is the corresponding elastic modulus, then $\mu\Delta l/lE^2$ depends solely upon the configuration of the system, and upon ϵ and its variation with Δl. The changes (Δl) are very small and the sources of error are numerous; consequently the results obtained are frequently quite discordant and at times even qualitatively contradictory.

For summaries and discussions, *v.* (**20, 50, 79, 81, 82**); for recent developments, *v.* (**2, 10, 14, 33, 34, 55, 57, 74, 75, 92.5, 123**); for bibliography, *v.* (**10, 100**).

Table 1.—Electrostriction

The following data are based upon the change in dimensions of a condenser when it is charged. This change frequently increases rapidly for several seconds; the values tabulated are presumably those approximately constant ones corresponding to an application of the field for 15 to 40 sec.

In column (2) the type of the condenser is indicated (c = cylindrical, s = spherical, p = plate) and the quantity corresponding to l in the formula below is stated; c_e = cylindrical condenser with electrodes supported by the dielectric.

Röntgen (**93**) found that all liquids expanded under the action of E; Quincke (**81, 84**) found that some contracted, the contraction for $(C_2H_5)_2O$, almond oil, and rape oil being marked.

For air and CO_2, Gans (**35**) found a reduction in pressure in an electric field, in rough agreement with the value predicted by theory. For other work with gases, *v.* (**20, 50, 66, 82**).

For other experimental work, *v.* (**2, 20, 34, 35, 55, 57, 63, 66, 69, 70, 82, 96, 97, 127**).

$\Delta l/lE^2 \equiv A \times 10^{-n}$. Unit of $A \times 10^{-n} = 1$ cm² cgse^{-2} = 1.113×10^{-5} cm² volt^{-2}.

Dielectric	Condenser	A	n	Lit.
Glass* (1)	c_e, length	5.2	13	(10)
(2)	c_e, length	5.6	13	(10)
(3)		1.3	13	(84)
(4)		2.3	13	(84)
(5)		5.7	13	(18)
(6)		4.4	13	(19)
(7)		7.1	13	(19)
(8)	s, volume	2.6†	7	(84)
Paraffin‡ (1)	c_e, length	8.4	11	(10)
(1)	c, length	9.4	11	(10)
Ebonite§	c_e, length	5.8 to 1.15	12 10	(10) (10)
	c, length	6.5	10	(10)
		1.0	9	(10)
Rubber‖ (1)	p, thickness	6.7	9	(10)
(2)	p, thickness	5.4	9	(10)
(3)	p, thickness	7.6	9	(10)

* Values for (1) and (2) obtained 15 sec after application of E; at 2 or 3 sec after application of E, A is only 4. From data obtained (**125, 126**) with various glass tubes, electrodes not supported by the glass, Adams (**2**) deduces $8\pi\mu\Delta l/lE^2 = -1.35$ to -3.78; *v. also* (**10, 57, 69, 70, 100**).

† Flint glass. $\Delta v/vE^2$ is unchanged by a variation of E in the ratio of 1 to 5.

‡ Values 35 to 40 sec after application of E; at 5 sec after application of E, A is only 4. Temperature, 24°C. Both recorded values are for same tube.

§ Various specimens of the c_e group have been treated so as to vary μ(1.7×10^9 to 27×10^9); the products of $A \times 10^{-n}$ by the corresponding values of μ are constant (=0.18). For the c group, μ lay between 1.3×10^9 and 1.7×10^9.

‖ (1) and (2) are vulcanized "para-normal" rubber; (3) is unvulcanized pure rubber. The volume of the plate does not change when E is applied.

[1] This section deals with data pertaining to electrostriction, piezoelectricity and pyroelectricity. All units are of the cgse system unless the contrary is stated.

Piezoelectricity.—In general, when an anisotropic dielectric having no center of symmetry is mechanically strained, it becomes electrically polarized; the direction and magnitude of the polarization (P) depend upon the nature of the crystal, upon the nature and amount of the strain and upon the direction of the strain with reference to the axes of the crystal. Conversely, when such a dielectric is subjected to an electric field (E), not only are stresses of an electrostrictive nature set up in it, but also others which are usually much larger and which depend upon both the direction and magnitude of E. These effects are described as *piezoelectric.* The production of polarization by strain is called the *direct* effect; the other is the *converse* effect.

From experiments with calcite ($CaCO_3$), dolomite ($CaMgC_2O_6$), beryl ($Be_3Al_2Si_6O_{18}$), topaz ($Al_2F_2SiO_4$), barite ($BaSO_4$), and celestite ($SrSO_4$), Voigt (**120**) concludes that crystals possessing a center of symmetry may possess "central-symmetrical" piezoelectricity. Also some investigators have observed what appears to be a piezoelectric effect for certain apparently non-crystalline substances such as beeswax and resin (**3, 28**), sheet rubber (**12, 85**), ebonite, glass, hornoid, sealing wax, celluloid and paraffin (**12**), but it is difficult to determine how much of the observed effect is due to frictional electricity and to the presence of very small piezoelectric crystals. The observations (**85**) lead to a value of the order 10^{-5} for the strain-constant d for sheet rubber; this is nearly a thousand times as great as the value for most piezoelectric crystals.

If P_x, P_y, P_z are the components of the polarization (electric moment per unit of volume), E_x, E_y, E_z, the components of E; x_x, y_y, etc., the six strain components; X_x, Y_y, etc., the six stress components; then

$$P_x = e_{11}x_x + e_{12}y_y + e_{13}z_z + e_{14}y_z + e_{15}z_x + e_{16}x_y$$
$$-P_x = d_{11}X_x + d_{12}Y_y + d_{13}Z_z + d_{14}Y_z + d_{15}Z_z + d_{16}X_y$$

The expressions for the components P_y, P_z are obtained from that for P_x by changing the first digit "1" of the subscript of each e to "2," and to "3," respectively: $-P_y$, $-P_z$ are obtained from $-P_x$ by changing similarly the subscripts of each d. For the converse effect:

$$x_x = d_{11}E_x + d_{21}E_y + d_{31}E_z$$
$$-X_x = e_{11}E_x + e_{21}E_y + e_{31}E_z$$

The other five equations of each set (y_y, z_z, y_z, z_x, x_y; and Y_y, Z_z, Y_z, Z_x, X_y) are obtained in order from these by changing the second digit (1) of the subscript of each d (or e) to 2, 3, 4, 5, 6, respectively. The d's and e's are called the piezoelectric constants, the d's being the *strain constants* and the e's the *moduli:* they are mutually related by equations involving the elastic constants of the crystal (**81, 82, 91, 117**). Excepting triclinic asymmetric crystals, in each special case certain of these 18 parameters are necessarily zero. Those which may not be zero are indicated in Table 2.

When the polarization is parallel to the stress producing it, it is described as a longitudinal effect; it exists only when one or more of the constants with subscripts 11, 22, 33 are finite.

When the polarization is perpendicular to the direction of the strain producing it, it is described as a transverse effect; it exists whenever one or more of the constants with subscripts 12, 13, 21, 23, 31, or 32 are finite, and also for certain directions of the stress when one or more of the constants with subscripts 14, 25, 36 are finite; *v.* (**15, 21, 25, 83, 117**).

Owing to the smallness of the effect and to various sources of error such as twinning,[1] faulty orientation of crystal plate being studied, presence of impurities, etc., the data available are in most cases somewhat discordant. For many substances, our exact knowledge is limited to the fact that the piezoelectric constants are not all zero.

For full bibliography, including applications, *v.* (**16**); for recent summary of information regarding piezo- and pyroelectricity, *v.* (**36**); for description of piezoelectric phenomena, general theory, and bibliography, *v.* (**20, 21, 24, 81, 82, 91, 117**); for more recent formulation of theory, *v.* (**7, 9, 11, 37, 48, 99, 110, 111, 112**); for applications to high-frequency circuits, *v.* (**15, 17, 27, 38, 59, 67, 78, 98**); for equations giving value of P for a pressure applied in an arbitrary direction, *v.* (**82, 91, 103, 117**); for representation of P by means of piezoelectric surfaces, *v.* (**1, 4, 51, 91, 103, 117**); for effect of hydrostatic pressure, *v.* (**117**); *cf.* (**56**); for discussion of second-order effects, *v.* (**82, 117, 119**).

A list of crystals for which piezoelectric effects have been observed, and their constants, are given in Table 3.

[1]Partially twinned crystals show a reduced piezoelectric effect; complete twinning removes the piezoelectric property altogether.

TABLE 2.—THE PIEZOELECTRIC CONSTANTS PRESENT FOR EACH CLASS OF CRYSTALS POSSESSING THE PIEZOELECTRIC PROPERTY

Excepting the plagihedral cubic class (**117**), all of the 21 classes of crystals having no center of symmetry are piezoelectric.

The parameters are denoted by their subscripts in accordance with the scheme of equations. A repetition of a subscript for any crystal class indicates that for this class the corresponding parameters have the same value. In writing the equations for the five trigonal classes, a factor 2 must precede each d corresponding to parameters 16 and 26, in all other cases the equations are written as above, those parameters corresponding to blanks in the table being necessarily zero.

Hex. = hexagonal, Rho. = rhombic, Mon. = monoclinic, P = polar

The coordinate axes are assumed to be orthogonal, to form a right-handed system, and to be directed as indicated in the footnotes.

True polar pyroelectric effects (p. 209) may be exhibited by classes 2, 4, 6, 9, 12, 14, 15, 17, 18, 19; for class 19, P_x, P_y, and P_z are all present; for 18, only P_x and P_y are present; for all the other classes, only P_z exists.

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
		Hex.*			Trigonal†					Tetragonal‡				Rho.‡			Mon.§		
Polarization	Parameter	Cubic‖	Polar	Trapezohedral	Tripyramidal polar	Holohedral	Polar	Trapezohedral	Tetartohedral	Tetartohedral polar	Polar	Trapezohedral	Tripyramidal polar	Sphenoidal	Tetartohedral	Polar	Sphenoidal	Polar	Clinohedral	Triclinic¶ asymmetric
P_z	11					11		11	11	11									11	11
	12					−11		−11	−11	−11									12	12
	13																		13	13
	14	14		14	14			14		14	14	14	14	14			14	14		14
	15		15		15		15			15	15		15		15	15		15		15
	16						−22		−22	−22									16	16
P_y	21						−22		−22	−22									21	21
	22						22		22	22									22	22
	23																		23	23
	24		15		15		15			15	−15		15		15	24		24		24
	25	14		−14	−14			−14		−14	14	−14	−14	14			25	25		25
	26					−11		−11	−11	−11									26	26
P_z	31		31		31		31			31	31		31		31	31		31		31
	32		31		31		31			31	−31		31		31	32		32		32
	33		33		33		33			33			33		33	33		33		33
	34																		34	34
	35																		35	35
	36	14									36			36			36	36		36

* z-axis coincides with the c-axis of 6-fold symmetry; where polar, the + direction is direction of the polarization produced by heating the crystal. The y-axis is ⊥ to a face of the first order prism.

† z-axis coincides with the c-axis of 3-fold symmetry. The y-axis and the + direction of the z-axis are as for hexagonal (*v.* *). Polarization of class 7 is not changed by hydrostatic pressure.

‡ Coordinate axes x, y, z coincide, respectively, with crystallographic axes a, b, c.

§ x-axis ‖ c-axis; z-axis ‖ b-axis; y-axis lies in obtuse angle between the a- and c-axes.

‖ Only the tetrahedral (1_a) and the tetartohedral (1_b) classes are piezoelectric.

¶ Only the asymmetric class is piezoelectric. No convention regarding directions of axes of coordinates.

Pyroelectricity.—The electrical polarization (P) of many substances is changed when the temperature of the substance is changed; this phenomenon is described as *pyroelectric*. $\delta P/\delta t$ is called the pyroelectric constant of the substance; it decreases with the temperature and perhaps vanishes at absolute zero.

Several types of pyroelectricity are distinguished. The most marked pyroelectric effects are exhibited by those crystals which have a vectorial (polar) structure defining, not merely a line, but a definite direction along that line. The type exhibited by such crystals is called the *polar* or *vectorial* type of pyroelectricity; it is the type commonly associated with the word "pyroelectric." This type can be exhibited only by crystals belonging to the classes 2, 4, 6, 9, 12, 14, 15, 17, 18, and 19 of Table 2. Another type, in which the effects are much smaller, is known as the *central* or *tensorial* type; it may be exhibited (**82, 91, 116, 117, 120, 121**) by changing uniformly the temperature of crystals which have a certain type of tensorial symmetry; this type of symmetry occurs in every crystal class except those of the cubic system.

As crystals which are pyroelectric are also piezoelectric, the deformations accompanying changes in temperature give rise to polarizations of piezoelectric origin. These *false* pyroelectric effects are superposed upon the *true* pyroelectric effects which result solely from changes of temperature, effects due to accompanying strain being eliminated. In general, any piezoelectric crystal, when deformed by a change in temperature, whether uniform or not, exhibits false pyroelectric effects. Those produced by non-uniform heating are the more common and are called the false pyroelectric effects of the first kind, those produced by uniform heating being called the false effects of the second kind. As the false effects are generally much greater than the true, it is difficult to determine the latter. Indeed, the true pyroelectric effect has been investigated only for tourmaline and its existence for that substance is questioned. The magnitude of the pyro effect observed depends markedly upon both the surface and the volume conductivity of the specimen (**61, 94, 114, 117**).

The converse, or "electro-caloric," effect (the change in temperature resulting from the application of an electric field) has been detected (**58, 102, 117**).

For general discussion of pyroelectricity, *v.* (**20, 41, 60, 81, 82, 83, 91, 117**); for its molecular theory, *v.* (**6, 7, 8, 20, 82, 83, 91, 110, 112, 117**); most complete quantitative data are by Ackermann (**1**), discussed by Boguslawski (**6**).

For data for specific substances, *see* Table 3.

In addition to the substances tabulated below, both pyro and piezo effects have been observed (**23, 30, 82, 91, 117, 120, 121**) in the following crystals possessing a center of symmetry: topaz ($Al_2F_2SiO_4$), barite ($BaSO_4$), beryl ($Be_3Al_2Si_6O_{18}$), calcite ($CaCO_3$), dolomite ($CaMgC_2O_6$) and celestite ($SrSO_4$); and by means of a high frequency method, in which the orientation of the axes of the crystal could not be determined, traces of the piezoelectric effect have been found (**38**) in the following crystals: proustite (Ag_3AsS_3), urea (CH_4N_2O), ammonium oxalate ($N_2H_8C_2O_4$), asparagine ($C_4H_8N_2O_3.H_2O$), ammonium acid tartrate ($NH_4HC_4H_4O_6$) pentaerythritol ($C_5H_{12}O_4$), tetraethylammonium iodide ($N(C_2H_5)_4I$), triphenylmethane ($CH(C_6H_5)_3$), potassium acid tartrate ($KHC_4H_4O_6$), magnesium sulfate ($MgSO_4.7H_2O$), ammonium acid phosphate ($NH_4H_2PO_4$), sodium tartrate ($Na_2C_4H_4O_6$), sodium sulfoantimonate ($Na_3S_4Sb.9H_2O$), nickel sulfate ($NiSO_4.6H_2O$) and zinc sulfate ($ZnSO_4.7H_2O$). For other crystals, *v.* (**43, 43.5, 44, 45, 46, 49, 64, 65, 68**). For piezoelectric effects with apparently non-crystalline substances, *v.* p. 208.

No observation of either kind of effect was found recorded for crystals of classes 3, 5, 8, 10, 11, 13, 14 (*v.* Table 2). Of the other classes, no direct piezo observation was found recorded for classes 2, 4, 9, 12, 15, 18, 19, but all crystals which exhibit pyro effects are also piezoelectric. Crystals of class 7 are not excited by hydrostatic pressure.

The numbers in the column "C. S." indicate the crystal class of the substance, in accordance with the numbers of Table 2. The presence of the mark "✓" in a column indicates that the corresponding effect has been actually observed, but the numerical value of the constant is not known with certainty; if the detected pyro effect is necessarily a "false" one, the "✓" is replaced by an "f;" blanks indicate that no record of observations was found. In column "C" is the symbol indicating the piezoelectric strain constant which has the value $A \times 10^{-8}$, A being the value adjacent to the symbol. For example, for tourmaline at room temperature, $d_{33} = 5.78 \times 10^{-8}$ (es/cm²)/(dyne/cm²). Units are cgse. Data for pyro effect refer to the total effect, the sum of the "true" and the "false."

TABLE 3.—A LIST OF SUBSTANCES FOR WHICH EITHER PIEZO- OR PYROELECTRIC EFFECTS HAVE BEEN OBSERVED; TOGETHER WITH THEIR CONSTANTS AT ROOM TEMPERATURE

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	A	Lit.
Variable	Tourmaline (*v.* Table 4)	6	1.1 1.3	(1)	d_{33}	5.78	(89, 115)
$Ba(CHO_2)_2$	Barium formate	16	f	(45)			(45)
$Ba(SbO)_2(C_4H_4O_6)_2.H_2O$	Barium antimonyl tartrate	12	✓	(104, 113)			(81, 113)
$(Be, Mn, Fe)_7Si_3O_{12}S$	Helvite	1_a	f	(43, 43.5)			(43, 43.5)
C	Diamond	1_a	0.0*	(113)		0†	(113)
$C_3H_8N_4O_4$	Methylene diisonitramine methyl ester $CH_2(N_2O_2.CH_3)_2$	15	✓	(81, 109)			
$C_4H_6O_6$	Tartaric acid	17	7.5	(47)	d_{33}‡	6.4	(103)
$C_4H_{12}N_2O_6$	Ammonium tartrate	17	2.84§	(1, 47)			(38)
$C_6H_3N_3O_7$	Picric acid	15	✓	(13)			
$C_6H_6O_2$	Resorcinol	15	7.7	(47)			(38)
$C_6H_{12}O_5$	Quercitol	17	✓	(81)			
$C_6H_{12}O_5.H_2O$	*d*-Rhamnose (isodulcitol)	17	3.63 0.505	(47)			
$C_6H_{16}ClN$	Triethylamine hydrochloride	2	✓	(42)			
$C_7H_7BrO_4$	Bromoshikimilactone	4	✓	(107)			
$C_{10}H_{15}NO$	Carvoxime $C_{10}H_{14}.NOH$	17	✓	(81)			
$C_{10}H_{13}Br_5O$	Carvone pentabromide	17	✓	(122)			

* Value is relative to tourmaline (kind not specified) as unity. † No trace of piezoelectricity. ‡ *v.* Table 7.

TABLE 3.—(*Continued*)

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	*A*	Lit.
$C_{10}H_{17}NO$	Fenchoneoxime	17	∠	(81)			
$C_{12}H_{22}O_{11}$	Saccharose (cane sugar)	17	0.53	(47)	d_{33}‡	−10.2	(51)
$C_{12}H_{22}O_{11}.H_2O$	Lactose	17	∠	(81)			
$C_{14}H_{10}O_2$	Benzil	7			d_{11}	24	(113)
$C_{14}H_{12}O$	Phenyl *p*-tolyl ketone $C_6H_5.CO.C_6H_4.CH_3$	6	∠	(5)			
$C_{15}H_{26}O$	Patchouli camphor	7(?)			d_{11}	0.14	(113)
$CaAl_2Si_3O_{10}.3H_2O$	Scolecite	18	0.99	(47)			
$2CaO.Al_2O_3.3SiO_2.H_2O$	Prehnite	15	∠	(92, 108)			
$3Ca_3P_2O_8.CaF_2$	Fluoroapatite	4	∠	(44)			
$K_2C_4H_4O_6.\frac{1}{2}H_2O$	Potassium tartrate	17	5.96§	(1, 47)			(38)
$KBrO_3$	Potassium bromate	6	∠	(107)			
$K_2S_2O_6$	Potassium dithionate	7	f	(46)			(46)
$KLiSO_4$	Potassium lithium sulfate	4	4.86§	(1, 47)			
$(KLiSO_4)_x + (KLiCrO_4)$	Mixture	4	∠	(105)			
$(KLiSO_4)_{18} + KLiMoO_4$	Mixture	4	∠	(105)			
$K_2SO_4 + Li_2CrO_4$	Mixture	4	∠	(105)			
$KLiSeO_4$	Potassium lithium selenate	4	∠	(105)			
$KNaC_4H_4O_6.4H_2O$	Rochelle salt (*v.* Table 6)	16	∠	(110, 111, 112)	d_{14} d_{14}	340 to 1180 8100	(80) (111)
$Li_2SO_4.H_2O$	Lithium sulfate	17	23.2§	(1, 47)			(38)
$Li_2SeO_4.H_2O$	Lithium selenate	17	17.17§	(1, 47)			
$LiNa_3(MoO_4)_2.6H_2O$	Lithium trisodium molybdate	6	∠	(113)	d_{33}	14	(113)
$LiNaSO_4$(anhydrous)	Lithium sodium sulfate	6	2.3§	(1, 47)			
$LiNa_3(SeO_4)_2.6H_2O$	Lithium trisodium selenate	6	5.38§	(1, 47)			
$6MgO.8B_2O_3.MgCl_2$	Boracite‖	1_a	0.07*	(32, 113)			(23, 24, 113)
$NaBrO_3$	Sodium bromate	1_b	f	(46)			(46)
$NaClO_3$	Sodium chlorate	1_b	f	(23, 31, 32, 46)	d_{14}	−4.8	(80); *cf.* (23, 32, 46)
$NaIO_4.3H_2O$	Sodium periodate	9	∠	(46)			
$Pb(CHO_2)_2$	Lead formate	16	f	(45)			(45)
$Pb(SbO.C_4H_4O_6)_2$	Lead antimonyl tartrate	4	∠	(106)			
$Rb_2C_4H_4O_6$	Rubidium tartrate	7			d_{11}	8.2	(113)
SiO_2	Quartz (*v.* Table 5)	7	0.50f*	(31, 113)	d_{11}	−6.9	(22, 95)
$Sr(CHO_2)_2$	Strontium formate	16	f	(45)			(45)
$Sr(HC_4H_4O_6)_2.4H_2O$	Strontium acid tartrate	19	0.73§ 6.7*	(1, 47, 113)			
$Sr(SbO.C_4H_4O_6)_2$	Strontium antimonyl tartrate	4	∠	(106)			
$SrS_2O_6.4H_2O$	Strontium dithionate	7	f	(46)			(46)
$2ZnO.SiO_2.H_2O$	Calamine (hemimorphite)	15	5.0*	(113); *cf.* (23)			
$ZnS(\beta)$	Sphalerite	1_a	0.13*	(30, 32, 113)	d¶	4.8	(113)

§ *v.* Table 8. ‖ Isotropic if $t > 265°C$. ¶ For pressure along an axis of 3-fold symmetry; the resulting polarization is in same direction.

TABLE 4.—TOURMALINE: PYRO- AND PIEZOELECTRIC CONSTANTS

The *z*-axis coincides with the ternary (optical) axis of the crystal, and the *x*-axis lies in any one of the three planes of trigonal symmetry. The positive direction of *z* passes through the end of the crystal which becomes charged positively when the crystal is uniformly heated. This end is called the "analogous" end of the crystal; frequently it is not possible, by mere inspection, to determine which is the analogous end (124). The opposite end is called the antilogous end. The values found for the constants vary considerably from one specimen to another; in general, those for the darker specimens are the smaller in numerical value. The permanent electrical polarization along the *z*-axis is about 8×10^4 cgse (87, 90, 91); hydrostatic pressure increases it about 8×10^{-8} cgse per barye (56). Whether tourmaline exhibits "true" pyroelectric effects is doubtful; Voigt (114, 117) thought the true effect amounted to 20% of the total, but Röntgen (94, 118) and Lindmann (61) decided that it is too small to measure. The values given below represent the total pyroelectric effect. Writing $\delta P/\delta t = a + 2b(t - t_0)$, where P = the polarization along the *z*-axis, and t and t_0 are final and initial temperatures, values of a varying, with the specimen, from 0.52 to 2.03, and of b varying from −0.000256 to +0.0117 were found (88, 91); experiments extended to $t = 160°C$. For pyroelectric data, *v.* (1, 81, 83, 91, 113, 117); for piezoelectric, *v.* (81, 89, 91, 114, 115, 117, 120). P = polarization, T = absolute temperature, $A_{15} \times 10^{-8} = d_{15}$, etc.; $B_{15} \times 10^4 = e_{15}$, etc. (*v.* p. 208). Unit of T = 1°K; of P, d, e = 1 cgse unit of appropriate kind.

Pyroelectric $\delta P/\delta T$

T	B. G.*	Y. G.*	R. R.*
23	0.04	0.08	0.08
88	0.142	0.289	0.300
198	0.652	0.974	0.982
253	0.935	1.205	1.219
274	1.005	1.243	1.270
293	1.060	1.281	1.313
(293)	1.057†	1.275†	1.324†
352	1.170	1.337	1.404
372	1.187	1.350	1.426
408	1.217	1.381	1.460
488	1.268	1.490	1.544
578	1.381	1.669	1.723
648	1.525	1.865	1.943

L. G.‡ (94)

T	20.5	79	194	273	313.5	291
$\delta P/\delta T$	0.037	0.20	0.66	0.96	1.10	1.13§

Piezoelectric Constants‖

A_{15}	11.04				B_{15}	7.40
A_{22}	−0.69	−0.94			B_{22}	−0.53
A_{31}	0.74	0.96			B_{31}	3.09
A_{33}	5.78	5.4	5.4	5.6	B_{33}	9.60
Lit.	(89, 115)	(94)	(113)	(71)	Lit.	(89, 115)

* B. G. = blue-green, Y. G. = yellow-green, R. R. = rose-red. Data from (1).

† Data from (47).

‡ L. G. = light-green, data from (94). With darker specimens he found values only 83 % of these; discussed in (118).

§ From (86) for 5 green Brazilian specimens: $\delta P/\delta T = 1.13–0.0104(T - 291)$.

‖ Vary but little with changes in pressure and temperature; between 20°C and the temperature of liquid air (62) and for pressures up to 22 megabarye (71), the variation of d_{33} lies within the limits of experimental error. From theoretical considerations, Keys (54) concludes that, for tourmaline, the adiabatic piezoelectric constants, corresponding to suddenly applied stress, are 1.5 times as great as the usual isothermal ones. $d_{15} = A_{15} \times 10^{-8}$, etc.; $e_{15} = B_{15} \times 10^{4}$, etc.

Table 5.—Quartz: Pyro- and Piezoelectric Constants

For information regarding all properties of SiO_2, *v.* (101)

The z-axis coincides with the crystallographic c-axis of 3-fold symmetry, the y-axis is ⊥ to a face of the hexagonal first order prism, and, in dextro crystals, the + direction of the x-axis is outward through one of the faces (commonly denoted by s) of the trigonal pyramid; in levo crystals, the direction of the x-axis with reference to the s-faces is reversed; in each case, the + direction of the y-axis is such as to form a right-handed system of orthogonal axes. At 573°C, ordinary SiO_2 (trigonal, trapezohedral), known as "α-quartz," becomes transformed to "β-quartz" (hexagonal, trapezohedral) and loses its pyro- and piezoelectric properties (11, 37, 77, 101). Owing to its crystal form, SiO_2 can have no "true" pyroelectric properties; $\delta P/\delta t$ is approximately proportional to the absolute temperature (73), and at room temperature is about half as great as the value for tourmaline (113). Twinning is common; dextro and levo crystals have equally strong electrical properties; hence, specimens which are completely twinned are not piezoelectric.

Quartz is not electrically excited by hydrostatic pressure. The value of d_{11} is probably unchanged by pressure parallel to x-axis; Nachtikal (71) found it to decrease by 0.16% per megabarye, but Röntgen and Joffé (95) found it was not changed by 0.4% by a pressure of 18 megabarye, and according to Karcher (53) it remains constant to within 0.1% for pressures ≤ 3450 megabarye.

At room temperatures d_{11} is practically independent of temperature. There is some evidence that it increases by about 20% as t goes from room temperature to 60°C, and then with a further increase in t it gradually decreases until at 573°C it vanishes (26.5, 79, 82, 86, 101). On cooling it reappears. On cooling from +17 to −193°C, d_{11} decreases by 1.2%; cooling from −193 to −253°C causes a change of less than 0.2% (73). Ze (127) reports that the piezoelectric deformation of quartz reaches a saturation value at a field intensity of about 520 cgse units. In the following, the best values are printed in bold-face. Unit of d_{11} and d_{14} = 10^{-8} cgse; of e_{11} and $e_{14} = 10^{4}$ cgse.

d_{11}	−6.32	−6.3	−6.45	−6.27	−6.54	−6.3	−6.31	**−6.90**
Lit.	(21,25)	(26)	(89)	(80)	(71)	(113)	(47)	(22)

d_{11}	**−6.94**	−6.4	d_{14}	**+1.7**	+1.45	+1.93	$e_{11} = -5.10$
Lit.	(95)	(127)	Lit.	(101)	(89)	(80)	$e_{14} = -1.35$

Piezoelectric Resonators.—From the density (2.654 g cm^{-3}) and the elastic constants (117) of quartz, the natural frequencies (ν) of compressional vibrations parallel to the edges of a quartz parallelepiped cut with its edges a, b, c parallel to the crystal axes x, y, z, are $\nu_x = 2.70 \times 10^5/a$, $\nu_y = 2.70 \times 10^5/b$, and $\nu_z = 3.08 \times 10^5/c$ cycle per sec if the lengths of the edges are a cm, b cm, and c cm. In each case the wave-length of the elastic wave in the crystal is twice that of the corresponding edge. Through the agency of d_{11}, the vibrations along x and y may be directly excited by a high-frequency electric field applied parallel to x. Also, through the same d_{11}, a transverse, or shear, mode of vibration may be excited by a high-frequency field parallel to y, the fundamental frequency being $\nu_{xy} = 1.79 \times 10^5/b$ cycle per sec. This vibration depends upon the rigidity of quartz for torsion about the z-axis. In all of these values for the frequency the effect of sectional area is ignored, but the computed frequencies agree fairly well with those observed; *v. also* (16, 26, 81, 95, 117).

Table 6.—Rochelle Salt ($KNaC_4H_4O_6.4H_2O$): Pyro- and Piezoelectric Constants

Axes x, y, z coincide, respectively, with crystallographic axes a, b, c. Electrical properties are complicated and are greatly affected by changes in temperature and humidity, and by the past history of the specimen; great differences between individual specimens (29, 52, 72, 110, 111, 112). Valasek (110, 111, 112) thinks it has "true" pyroelectric properties although the crystal form indicates that they can not exist; his computations (110) indicate a permanent electrical polarization of the order of 50 cgse units; *v. also* (23). Rochelle salt (potassium sodium tartrate) is not electrically excited by hydrostatic pressure; its d_{14} is the largest known piezoelectric constant; *v.* especially (72). Unit of d_{14}, d_{25}, and $d_{36} = 10^{-6}$ cgse. Note: In other tables the unit, or common factor, is 10^{-8}.

t	−70	−50	−30	−20	−10	0	10	20	30	40	°C
d_{14}	0.17	0.17	0.65	10.8	60.7	67.5	74.2	81.0	10.8	4.1	(112)

The maximum is much greater than that recorded by any other observer. Later observations (112.5) indicate that with increasing t, d_{14} increases rapidly from a very low value to about 23 at −20°C, increases slightly from −20 to +25°C, and then decreases rapidly. Between −60 and +30°, d_{25} and d_{36} increase linearly with t, their rates being, respectively, 6.8×10^{-9} and 3.1×10^{-10} cgse unit per 1°C (112.5).

Near 20°C, Pockels (80) finds d_{14} = 3.40 to 11.80; $d_{25} = -1.65$, and $d_{36} = 0.35$.

From these data and the elastic constants (66.5) it is found that $e_{14} = 56 \times 10^4$ to 194×10^4, $e_{25} = -5.33 \times 10^4$, and $e_{36} = 4.34 \times 10^4$ cgse units.

From the density (1.767 g cm^{-3}) and the elastic constants (66.5) the velocity of compressional waves in a bar of Rochelle salt cut with its length perpendicular to the x-axis and at 45° with the y and z axes is found to be 3.98×10^5 cm/sec. Hence, natural frequency (ν) of such vibrations in a bar a cm long is $1.99 \times 10^5/a$ cycle per sec; experimental values may be expected to differ rather widely from this value (17).

TABLE 7.—PIEZOELECTRIC CONSTANTS OF TARTARIC ACID ($C_4H_6O_6$) AND OF CANE SUGAR ($C_{12}H_{22}O_{11}$)

Room temperature; precision about 3%; system = monoclinic polar. $d_{14} = A_{14} \times 10^{-8}$; etc. Unit of d = 1 cgse.

Formula	A_{14}	A_{15}	A_{24}	A_{25}	A_{31}	A_{32}	A_{33}	A_{36}	Lit.
$C_4H_6O_6$.....	−24	28.3	28.5	−36.5	1.95	5.9	6.4	3.8	(103)
$C_{12}H_{22}O_{11}$.....	1.27	−12.6	−7.2	3.75	2.21	4.4	−10.2	−2.62	(51)

TABLE 8.—PYROELECTRIC EFFECT: VARIATION WITH TEMPERATURE (1)

T = absolute temperature, °K. Unit of $\delta P/\delta t$ = 1 cgse unit

T	23	88	198	253	274	293	293*	352
Formula	$\delta P/\delta t$							
$Sr(HC_4H_4O_6)_2$.-								
$4H_2O$†.....	0.04	0.12	0.45	0.64	0.69	0.728	0.73	0.825
$NaLiSO_4$.....	0.12	0.29	0.88	1.63	2.03	2.26	2.31	2.74
$C_4H_{12}N_2O_6$‡....	0.15	0.31	1.18	2.41	2.58	2.84	2.84	3.42
$KLiSO_4$.....		0.69	2.50	4.09	4.51	4.85	4.88	5.35
$Na_3Li(SeO_4)_2$.-								
$6H_2O$.....	0.35	0.93	2.94	4.58	5.07	5.38	5.38	6.37
$K_2C_4H_4O_6$.-								
$\frac{1}{2}H_2O$†.....	0.39	1.00	3.32	5.10	5.60	5.96	5.98	6.89
$Li_2SeO_4.H_2O$...	0.92	2.30	9.87	14.54	16.00	17.17	17.14	19.35
$Li_2SO_4.H_2O$....	1.21	3.81	12.24	18.42	20.45	23.27	23.18	26.90

* (47). † Tartrate. ‡ Ammonium tartrate.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ackermann, *8*, **46**: 197; 15. (2) Adams, *3*, **22**: 889; 11. (3) Adams, *143*, **204**: 469; 27. (4) Bidlingmaier, *Diss.*, Göttingen, 1900. (5) Bodewig, *8*, **158**: 232; 76. (6) Boguslawski, *63*, **15**: 283, 569, 805; 14. (7) Born, *96*, **7**: 217; 21. *Atomtheorie des festen Zustandes.* Leipzig, Teubner, 1923. (8) Born, *63*, **23**: 125; 22. (9) Born and Borman, *8*, **62**: 218; 20.

(10) Bouchet, *Thesis*, Paris, 1919. (11) Bragg and Gibbs, *5*, **109**: 405; 25. (12) Brain, *67*, **36**: 81; 24. (13) Brugnatelli, *94*, **24**: 274; 95. (14) Bruhat and Pauthenier, *51*, **6**: 1; 25. (15) Cady, *529*, **10**: 83; 22. (16) Cady, *529*, **16**: 521; 28. (17) Cady, *48*, **10**: 475; 25. (18) Cantone, *22*, **4**: 344, 471; 88. (19) Cantone and Sozzani, *59*, **12**: 155; 00.

(20) Chwolson, *Lehrbuch d. Physik*, **IV.** Braunschweig, Vieweg und Sohn, 1925. (21) Curie, *Oeuvres.* Paris, Gauthier-Villars, 1908. (22) Curie, *Traité de Radioactivité*, **I.** Paris, Gauthier-Villars, 1910. (23) Curie and Curie, *34*, **91**: 383; 80. (24) Curie and Curie, *51*, **1**: 245; 82. (25) Curie and Curie, *51*, **8**: 149; 89. (26) Czermak, *75*, **96**: 1217; 87. (26.5) Dawson, *2*, **29**: 532; 27. (27) Dye, *67*, **38**: 399, 457; 26. (28) Eguchi, *219*, **2**: 169; 20. (29) Frayne, *2*, **20**: 97; 22. **21**: 348; 23.

(30) Friedel, *191*, **2**: 31; 79. (31) Friedel and Curie, *191*, **5**: 282; 82. *34*, **96**: 1262, 1389; 83. (32) Friedel and Curie, *34*, **97**: 61; 83. *191*, **6**: 191; 83. (33) Frivold, *Fysisk tidsskrift*, **20**: 119; 22. *63*, **22**: 603; 21. (34) Frivold and Hassel, *63*, **24**: 82; 23. (35) Gans, *8*, **11**: 797; 03. (36) Geiger and Scheel, *Handbuch d. Physik*, **XIII.** Berlin, Springer, 1928. (37) Gibbs, *5*, **110**: 443; 26. (38) Giebe and Scheibe, *96*, **33**: 760; 25. (39) Giebe and Scheibe, *96*, **34**: 347; 25.

(40) Giebe and Scheibe, *101*, **47**: 380; 26. (41) Groth, *Physikalische Krystallographie.* Leipzig, Engelmann, 1905. (42) Groth, *Chemische Krystallographie*, **I.** Leipzig, Engelmann, 1906. (43) Hankel, *211*, **12**: 549; 84. (43.5) Hankel, *94*, **9**: 414; 84. (44) Hankel, *8*, **19**: 818; 83. (45) Hankel, *211*, **24**: 469; 99. (46) Hankel and Lindenberg, *211*, **18**: 359; 93. **21**: 9; 95. (47) Hayashi, *Diss.*, Göttingen, 1912. (48) Heckmann, *96*, **33**: 646; 25. (49) Hintze, *Handbuch der Mineralogie.* Leipzig, Veit, 1897.

(50) Hirsch, *in B90*, **I.** (51) Holman, *8*, **29**: 160; 09. (52) Isely, *2*, **24**: 569; 24. (53) Karcher, *31A*, **18**: 257; 22. *143*, **194**: 815; 22. (54) Keys, *3*, **46**: 999; 23. (55) Kliefoth, *96*, **39**: 402; 26. (56) Koch, *8*, **19**: 567; 06. (57) Kemble, *2*, **7**: 614; 16. (58) Lange, *Diss.*, Jena, 1905. (59) von Laue, *96*, **34**: 347; 25.

(60) Liebisch, *Grundriss der physikalischen Krystallographie.* Leipzig, Veit, 1896. (61) Lindman, *8*, **62**: 107; 20. (62) Lissauer, *Diss.*, Munich, 1907. (63) Lorberg, *8*, **21**: 300; 84. (64) Lucas, *51*, **4**: 491; 23. (65) Lucas, *34*, **178**: 1890; 24. (66) Mache, *75*, **107**: 708; 98. (66.5) Mandell, *5*, **116**: 623; 27. (67) Meissner, *529*, **15**: 281; 27. *97*, **7**: 585; 26. **8**: 74; 27. (68) Miers, *269*, **10**: 273; 94. (69) More, *3*, **50**: 198; 00. **2**: 527; 01.

(70) More, *3*, **6**: 1; 03. **10**: 676; 05. (71) Nachtikal, *188*, **1899**: 109. (72) Nicolson, *129*, **38**: 1467; 19. (73) Onnes and Beckman, *168*, **No. 132f.** *64P*, **15**: 1380; 12. (74) Pauthenier, *51*, **5**: 312; 24. (75) Pauthenier, *34*, **182**: 121; 26. (76) Perrier, *149*, **41**: 492; 16. (77) Perrier and de Mandrot, *34*, **175**: 622, 1006; 22. (78) Pierce, *65*, **59**: 81; 23. **60**: 271; 25. (79) Pockels, *Arch. Math. Phys.*, **12**: 57; 93.

(80) Pockels, *188*, **1894**: 1. (81) Pockels, *in B76*, **IV.** (82) Pockels, *in Encyklopädie der Math. Wiss.*, **V.** Leipzig, Barth, 1907. (83) Poynting and Thomson, *Textbook of physics*, **IV.** London, Griffin, 1920. (84) Quincke, *8*, **10**: 161, 513; 80. **19**: 545; 83. (85) Richards, *2*, **22**: 122; 23. (86) Riecke, *8*, **28**: 43; 86. (87) Riecke, *8*, **31**: 889; 87. (88) Riecke, *8*, **40**: 264; 90. (89) Riecke and Voigt, *8*, **45**: 523; 92.

(90) Riecke, *63*, **13**: 409; 12. (91) Riecke, *in B90*, **I.** (92) Riess and Rose, *524*, **1843**: 59. (92.5) Rocard, *51*, **8**: 385; 27. (93) Röntgen, *8*, **11**: 780; 80. (94) Röntgen, *8*, **45**: 737; 14. (95) Röntgen and Joffé, *8*, **41**: 449; 13. (96) Sacerdote, *Thesis*, Paris, 1899. *51*, **8**: 457; 99. (97) Sacerdote, *51*, **10**: 196; 01. (98) Scheibe, *Z. f. Hochfrequenztechn.*, **28**: 15; 26. (99) Schrödinger, *75*, **121 IIa**: 1937; 12.

(100) Shearer, *2*, **14**: 89; 02. (101) Sosman, *B91*. (102) Straubel, *188*, **1902**: 161. (103) Tamaru, *63*, **6**: 379; 05. (104) Traube, *188*, **1892**: 362. (105) Traube, *190*, **1892 II**: 58. **1894 I**: 171. (106) Traube, *190B*, **8**: 269; 93. (107) Traube, *94*, **23**: 577; 94. (108) Traube, *190B*, **9**: 134; 95. (109) Traube, *94*, **29**: 595; 98.

(110) Valasek, *2*, **17**: 475; 21. (111) Valasek, *2*, **20**: 639; 22. (112) Valasek, *2*, **19**: 478, 529; 22. (112.5) Valasek, *166*, **65**: 235; 27. (113) van der Veen, *Thesis*, Delft, 1911. (114) Voigt, *8*, **66**: 1030; 98. (115) Voigt, *188*, **1898**: 166. (116) Voigt, *188*, **1905**: 394. (117) Voigt, *Lehrbuch der Krystallphysik.* Leipzig, Teubner, 1910. (118) Voigt, *8*, **46**: 221; 15. (119) Voigt, *8*, **48**: 433; 15.

(120) Voigt, *63*, **17**: 287, 307; 16. (121) Voigt, *63*, **18**: 59; 17. (122) Wallach, *18*, **286**: 119; 95. (123) Webb, *1*, **48**: 2589; 26. (124) Worobiev, *94*, **33**: 263; 00. (125) Wüllner and Wien, *8*, **9**: 1217; 02. (126) Wüllner and Wien, *8*, **11**: 619; 03. (127) Ze, *51*, **9**: 13; 28.

THERMOELECTRICITY

A. E. Caswell

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If two metallic conductors, M and R, are connected in series so as to form a closed circuit, and if one junction is kept at the temperature, 0°C and the other at the temperature, $t (t \neq 0)$, there will be a *thermo emf* ${}_ME_R$ around the circuit. By convention, ${}_ME_R$ is regarded as positive if the current so produced flows from M to R at the junction which is at 0°C. ${}_RE_M = -{}_ME_R$; ${}_ME_R + {}_RE_S = {}_ME_S$. ${}_MQ_R \equiv \partial {}_ME_R/\partial t$ is called the *thermoelectric power* of M with respect to R. As a current I passes through a junction from R to M an amount of heat $({}_MP_R)I = T({}_MQ_R)I$ is absorbed per second; ${}_MP_R$ is the *Peltier coefficient* of M with respect to R, and T is the absolute temperature corresponding to t. If ${}_MQ_R$ is negative, so is ${}_MP_R$, and heat is evolved when current flows from R to M. The equations are valid for any consistent system of units; in particular, if E is expressed in volts and I in amperes, the heat is expressed in joules. If, in an unequally heated homogeneous conductor, a current, I, flows from a point where the temperature is t_2 to another where it is t_1, $t_2 > t_1$, an amount of heat $H = \int_{t_1}^{t_2} I\sigma dt$ will be absorbed per second, apart from the usual Joule heating effect. σ is the *Thomson coefficient* of the metal in question; it may be either positive or negative. Denoting by a subscript the metal to which σ refers, $\sigma_M - \sigma_R = -T\,(\partial^2 {}_ME_R/\partial t^2)$.

All four quantities, ${}_ME_R$, ${}_MQ_R$, ${}_MP_R$ and σ_M are profoundly affected by anything which alters the structure of the metals to which they refer. They are greatly affected by impurities, heat treatment, drawing, rolling, pressure, tension and magnetization. Only very rarely will identical thermoelectric curves be found for two couples formed from the same pair of metals.

For a bar cut from a crystal, the value of Q will, in general, depend upon the direction which the length of the bar makes with the axis of the crystal. When Q does depend upon this direction, the bar, unless cut parallel to one of the principal thermoelectric axes, exhibits another distinct thermoelectric property, in virtue

of which the longitudinal passage of an electric current through the bar is accompanied by an absorption of heat at one side of the bar and an evolution of heat at the opposite side, the two sides being kept at the same, or essentially the same, temperature. This is known as the *transverse Peltier effect.* (For a rectangular bar of Bi cut with its length at 45° to the axis of the crystal, distance between sides which became unequally heated = 1.55 mm, distance between other two sides = 2.64 mm, it was observed that $\Delta t = 0.267$°C per ampere of longitudinal current, the bar being exposed to the air and at room temperature (16).) Conversely, a difference in temperature of the two sides gives rise to a longitudinal emf.

TABLE 1.—THERMO EMF AND THERMOELECTRIC POWER OF ELEMENTARY SUBSTANCES

$_ME_R = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$; one junction at 0°C.

$_MQ_R = d(_ME_R)/dt = a + bt(10)^{-2} + ct^2(10)^{-5}$.

$_MP_R = T(_MQ_R)$ = Peltier coefficient; difference in the Thomson coefficients is $(\sigma_M - \sigma_R) = T d(_MQ_R)/dt$; T = absolute temperature corresponding to temperature t. The tabulated coefficients apply for all values of t between t_1 and t_2. For other notation, *see* introduction.

The numbers in the "Error" column indicate the possible departures (±) of observed value of E from that calculated by means of the coefficients; unit is 1%, unless another is indicated. The expression $\left.\begin{matrix}-0.38\\-0.53\end{matrix}\right\}$ indicates that the quantity varies from −0.38 to −0.53. Unit of $E = 1\mu v = 10^{-6}$ volt; t_1, t_2 = centigrade temperature, °C.

M	*R*	t_1	t_2	a	b	c	Error	Lit.
Ag[e]	Pb	−270	+ 100	+ 2.947	+ 0.6782	− 0.186	1	(31)
Ag	Pb	0	+ 200	+ 3.3383	+ 0.847		1.5	(59)
Ag[cc]	Pb	0	+ 100	+ 2.50	+ 1.15		1	(76)
Ag	Pt	0	+ 900	+ 3.04	+ 2.01		1.5	(65)
Al[b]	Pb	−200	+ 100	− 0.4717	+ 0.2718	− 2.386	1	(31)
Al[h]	Pb	0	+ 200	− 0.4960	+ 0.1734		1.5	(59)
Al[e]	Pb	0	+ 100	− 0.38 / − 0.53	− 0.01 / + 0.21	− 2.82		(76) / (17)
Al	Pt	0	+ 800	− 0.7982	− 0.9072	− 0.6717	1.5	(65)
Au	Pb	−260	0	+ 2.90	+ 0.68		1.5	(80)
Au	Pb	0	+ 200	+ 2.90	+ 0.934		1.5	(17, 59, 76)
Bi	Pb	−200	+ 100	− 81.845	+ 0.599	+ 162.5	1	(31)
Bi[e]	Pb	−200	+ 100	− 43.688	− 46.47	− 38.72	1	(31)
Bi[e]	Pb	0	+ 100	− 74.42	+ 3.2		1.5	(17)
Bi	Pt	0	+ 268	− 61.95	+ 4.502	+ 26.82	1.5	(65)
Bi	Pt	+300	+ 800	+ 15	d = −17 900		1.5	(65)
Bi[w]	Cu	+ 20	+ 100	− 55.0	− 3.12	(0.0°)*	1.0	(17)
Bi[w]	Cu	+ 20	+ 100	− 56.6	− 2.50	(5.5°)*	1.0	(17)
Bi[w]	Cu	+ 20	+ 100	− 59.0	− 10.00	(10.0°)*	5.0	(17)
Bi[w]	Cu	+ 20	+ 100	− 61.4	− 6.25	(17.7°)*	1.0	(17)
Bi[w]	Cu	+ 20	+ 100	− 61.1	− 8.75	(21.1°)*	1.0	(17)
C[f]	Pb	−200	+ 100	+ 11.056	+ 3.578	+ 5.379	1	(31)
C	Pt	0	+ 560	− 6.0072	+ 16.92	− 0.2274	2	(53)
Ca	Cu	0	+ 100	− 9.35	− 3.1		1	(60)
Ca[d]	Pb	0	+ 400	− 8.20	− 2.9			(77)
Cd	Pb	−200	+ 100	+ 3.059	+ 2.856	+ 9.00	1	(31)
Cd[h]	Pb	0	+ 200	+ 2.619	− 1.787		1.5	(59)
Cd[e]	Pb	0	+ 100	+ 2.85	+ 3.89		1	(76)
Cd	Pt	0	+ 320	+ 0.390	+ 0.38		0.5	(65)
Cd	Pt	+320	+ 700	+ 1.5	d = −164		0.5	(65)
Ce[e]	Cu	0	+ 200	+ 4.39	− 1.26		2	(44)
Co[i]	Cu	0	+ 280	− 20.51	− 5.4		2	(64)
Co	Cu	+340	+ 550	− 24.75	− 2.7		2	(64)
Co	Cu	+580	+ 900	− 62.6	+ 4.34	(+10 310)†		(64)
Co	Cu	0	+ 280	− 23.24	− 8.26		1.5	(66)
Co	Pt	0	+1 200	− 10.7	− 5.70	+ 7.50	2	(68)
Cs	Pt	−200	− 75	+ 4.66[p]	+ 5.49[p]			(11)
Cs	Pt	− 75	+ 5.8	+ 3.14	+ 3.453		(?)	(11)
Cs	Pt	+ 27.4	+ 300	+ 15.73[p]	− 4.93[p]			(11)
Cs	Pb	−183	0	+ 0.66	− 0.10			(19)
Cs	Pb	+ 28	+ 100	+ 7.735	− 3.34			(19)

TABLE 1.—(*Continued*)

M	*R*	t_1	t_2	a	b	c	Error	Lit.
Cu[j]	Pb	−270	+ 200	+ 2.705	+ 0.7866	+ 1.773	1	(31, 59, 62, 80)
Cu[k]	Pb	0	+ 100	+ 2.76	+ 1.22		1	(76)
Cu	Pt	0	+ 900	+ 3.130	+ 2.460		1	(65)
Fe	Pb	−260	− 200	− 51.34	− 20.4	(−2 912)†	0.25	(80)
Fe[m]	Pb	−230	+ 100	+ 16.65	− 2.966	− 26.75	1	(17, 31, 80)
Fe	Pt	0	+1 000	*v.* Table 2				
Fe[e]	Cu	0	+ 700	+ 13.7	− 7.80	+ 6.60	1	(18)
Ge	Pt	−200	+ 125	+ 302.5	+ 72.5		1	(11)
Ge	Pt	+135	+ 275	− 219‡	+ 766	−2 391		
Ge	Pt	+275	+ 500	+1 422§	− 702	+ 762		
Ge	Pt	+500	+ 700	− 362	+ 31.2	(+204.9)‖		(11)
Hg	Pb	0	+ 200	− 8.8103	− 3.333		1.5	(59)
In	Pb	0	+ 100	+ 2.40	+ 0.190			(33.1)
Ir	Pt	+250	+1 500	− 7.282	− 1.108	(+248)‖		(45)
Ir[h]	Pb	− 80	+ 100	+ 2.44	− 0.28		1	(19)
K	Pb	−183	0	− 11.33	− 3.76		1	(19)
K	Pt	−200	− 113	− 4.64[p]	+ 2.41[p]			(11)
K	Pt	−113	+ 53	− 8.09	− 0.59		(?)	(11)
K	Pt	+ 62.5	+ 300	− 5.41[p]	− 0.017[p]			(11)
Li	Pt	−200	+ 50	+ 14.37	+ 8.76			(11)
Li	Pt	+ 50	+ 168	+ 16.71[p]	+ 4.08[p]		(?)	(11)
Li	Pt	+183	+ 300	+ 20.57[p]	+ 5.39[p]			(11)
Mg	Pb	−200	+ 100	− 0.2010	+ 0.2572	− 1.677	1	(31)
Mg[h]	Pb	0	+ 200	− 0.120	+ 0.193		1.5	(59)
Mg	Pt	0	+ 700	+ 5.0	+ 1.444		1	(68)
Mo	W	0	+1 060	+ 4.61	+ 0.872		4	(60)
Mo	W	+950	+2 250	+ 24.5¶	− 188.6		5.0	(57.1)
Mo	Pb	0	+ 100	+ 5.892	+ 4.334	− 7.50	1.5	(17)
Mo	Pt	0	+1 200	+ 13.0	+ 2.96		2.5	(68)
Na	Pt	−200	+ 8.1	− 0.882	+ 4.104			(11)
Na	Pt	+ 8.1	+ 84.7	− 0.482[p]	− 0.833[p]		(?)	(11)
Na	Pt	+ 97	+ 300	+ 3.222[p]	− 2.094[p]			(11)
Na	Pb	−183	0	− 4.16	− 1.44			(19)
Ni[n]	Pb	−200	+ 100	− 16.325	− 5.346	+ 5.703	1	(31)
Ni[h]	Pb	0	+ 200	− 19.067	− 3.022		1.5	(59)
Ni	Pb	−260	0	− 17.633	− 5.016	+ 1.137	0.02	(80)
Ni	Pt	0	+ 313	− 2.891	+ 0.622		0.5	(65)
Ni	Pt	+313	+ 900	+ 0.484**	− 0.366	+ 0.1616	0.5	(65)
Ni	Pt	0	+1 200	− 17.12	+ 2.46	− 2.193	2	(68)
Pd	Pb	−200	+ 100	− 7.409	− 3.922	+ 12.65	1	(31)
Pt[h]	Pb	−200	+ 300	− 3.038	− 3.248	+ 8.409	1.5	(17, 31, 59)
Pt[q]	Pb	0	+ 100	− 1.788	− 3.460	+ 12.6	1	(17)
Pt	Pb	−260	0	− 6.677	+ 0.1528		0.5	(80)
Rb	Pt	−200	− 25	− 3.537[p]	+ 1.851[p]			(11)
Rb	Pt	− 25	+ 23.2	− 4.332	− 1.328		(?)	(11)
Rb	Pt	+ 37.2	+ 300	+ 2.141[p]	− 5.76[p]			(11)
Rb	Pb	−183	0	− 8.26	− 3.02			(19)
Rb	Pb	+ 38	+ 100	− 0.28[p]	− 6.00[p]			(19)
Rh[h]	Pb	− 78	+ 100	+ 2.17	+ 0.05			(19)
Rh	Pt	0	+1 300	+ 6.27	+ 1.612	+ 0.1797	2.5	(45)
Sb	Pt	0	+ 630	+ 46.24	+ 6.362	− 14.33	2	(65)
Sb	Pt	+650	+ 711		+2 100[p]			(65)
Sb[r]	Pb	0	+ 100	+ 35.58	+ 14.50		1.5	(41, 76)
Se[v]	Pb	+ 10	+ 100	b = +99 000[p] to 114 000[p]				(46.1)
Si	Pb	−200	+ 350	− 408.2	− 46.96	+351.0	3	(79)
Sn	Pb	−260	0	− 0.11	+ 0.264		3 mcv.	(80)
Sn	Pb	−200	+ 100	+ 0.0684	+ 0.0038	− 0.266	1%	(31)
Sn	Pb	0	+ 100	− 0.111	+ 0.040		1	(76)
Sn	Pb	0	+ 100	+ 0.230	− 0.134		1	(17)
Sn	Pb	0	+ 200	− 0.168	+ 0.187		1.5	(59)
Sn	Pt	0	+ 415	+ 2.870	+ 2.3		0.5	(65)
Sn	Pt	+415	+ 600	+ 13.0	d = −2 200		0.5	(65)
Ta	Cu	−200	+ 100	− 3.358	− 1.343		3 mcv.	(27)
Ta[s]	Pt	0	+ 400	+ 2.20	+ 2.46		2%	(64)
Ta	Pt	0	+1 200	+ 2.0	+ 2.64		3	(68)
Te	Cu	Qu$<_{352}$, Q_{18} = +434††						(41)
		Au$<_{352}$, Q_{18} = +229††						(41)
		Ht$>_{353}$, Q_{18} = +160††						(41)
Te[w]	Cu	+ 20	+ 100	+ 191.2	− 275.0	(0.0°)§§	1.0	(17)
Te[w]	Cu	+ 20	+ 100	+ 148.7	− 168.9	(7.5°)§§	1.0	(17)
Te[w]	Cu	+ 20	+ 100	+ 277.2	− 361.2	(12.5°)§§	1.0	(17)
Tl[u]	Pb	0	+ 100	+ 2.14	− 0.77		1	(76)
Tl	Pb	0	+ 100	+ 1.659	− 0.268	− 1.68	1	(17)
Tl	Pt	0	+ 310	+ 5.18	+ 1.34		1	(65)
Tl	Pt	+310	+ 404	− 156‡‡	+ 70.66	− 111.9	1	(65)
W	Pb	0	+ 100	+ 1.594	+ 3.41		1	(17)

TABLE 1.—(*Continued*)

M	*R*	t_1	t_2	a	b	c	Error	Lit.
W	Cu	−200	+ 300	− 1.080	+ 2.334	+ 2.375	5 mcv.	(27)
W[t]	Cu	0	+ 630	− 1.12	+ 1.695		2%	(64)
W	Pt	0	+1 200	+ 9.4	+ 3.68		2	(68)
W	Ta	+950	+2 430	+ 5.21‖‖	+ 590		2.0	(57.1)
Zn	Pb	−260	0	+ 3.096	+ 3.191	+ 10.99	1	(80)
Zn[w]	Cu	+ 20	+ 100	− 0.919	+ 0.28	(35.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	− 1.012	+ 0.93	(46.5°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	− 0.725	+ 0.75	(48.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	− 0.400	+ 0.59	(57.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	− 0.200	+ 0.75	(60.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	+ 0.154	+ 0.82	(80.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	+ 0.135	+ 0.97	(83.0°)§§	1.0	(17)
Zn[w]	Cu	+ 20	+ 100	+ 0.232	+ 0.97	(86.5°)§§	1.0	(17)
Zn[t]	Pb	−200	+ 100	+ 2.607	+ 1.074	+ 1.39	1	(31)
Zn	Pb	0	+ 100	+ 3.047	− 0.99		1.5	(17)
Zn[c]	Pb	0	+ 250	+ 3.181	− 0.113		1.5	(59)
Zn	Pt	0	+ 450	+ 5.74	+ 3.30		1.5	(31, 59, 65)
Zn	Pt	+450	+ 700	− 17	d = +1 820		1.5	(65)

* Angle between basal cleavage plane and direction of current.
† Value of d; c = 0.
‡ d = 26 716.
§ d = −87.46.
‖ Value of d; c = 0.
¶ d = −12 400.
** d = −600.
†† $Qu_{<352}$, [An<352] = quenched [annealed] from below 352°C; $Ht_{>353}$ = after heating above 353°C; $Q_{18} = Q$ at 18°C.
‡‡ d = +12 420.
§§ Angle between crystal axis and direction of current.
‖‖ d = 1 320.
[a] Annealed. [b] 99% pure. [c] Commercial. [d] 99.57% pure. [e] Electrolytic. [f] Filament of incandescent lamp. [g] Cold-drawn and hammered. [h] Heraeus made. [i] 99.8% Co, 0.2% Si, traces Fe. [j] Electrolytic, cold-drawn, annealed in hydrogen. [k] Pure "Swedish," hard-drawn, used for gold refining. [m] Very soft, annealed transformer Fe. [n] Deposited from nickel carbonyl. [o] 97.7% Ce, 1.2% Fe, remainder cerium oxide and cerium carbide. [p] Applies to equation for Q only. [q] Baker's platinum. [r] Used in cast form, solid rods soldered end to end. [s] Slight traces of carbon. [t] Traces of Fe. [u] 97.9% Tl, 1.5% Pb, traces of Cu and As. [v] Se in darkness; in light sufficient to increase its conductivity 600%, Q is decreased by 6%. [w] Single crystal.

TABLE 2.—THERMOELECTRIC POWER ($_{Fe}Q_{Pt}$) OF COUPLES OF PURE IRON AND PLATINUM (22)

The pure iron contained 99.968 Fe, 0.009 C, 0.009 S, 0.001 P, 0.006 Si, 0.001 Mn and 0.006 Cu; the platinum was purest Heraeus Pt. For the Fe, the A_1 transformation point near 700°C, due to C, is absent; A_2 is at 768°C, Ar_3 and Ac_3 are at 900 and 910°C, respectively. Unit of $Q = 1\mu v/°C = 10^{-6}$ volt/°C; t = centigrade temperature, °C.

t	$_{Fe}Q_{Pt}$	t	$_{Fe}Q_{Pt}$	t	$_{Fe}Q_{Pt}$
0	+19.5	775	+18.1	Temp. rising	
100	+18.1	800	+18.4	1000	+12.6
200	+15.4	880	+19.4	Temp. falling	
300	+11.7	Temp. rising		930	+11.1
400	+ 9.5	900	+19.7	920	+10.9
500	+ 9.1	910	+19.4	910	+10.8
600	+10.8	920	+16.6	900	+17.5
700	+14.3	930	+11.4		

TABLE 3.—THERMOELECTRIC POWER (Q) AND THERMO EMF (E) OF ALLOYS (MAINLY BINARY ALLOYS)

For list of commercial alloys and miscellaneous mixtures, *see* end of table. $Q = a + bt(10)^{-2} + ct^2(10)^{-5}$; $E = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$, one junction at 0°C; E can not be obtained from Q unless the value of d is known, but d is generally zero if no transformation point occurs between 0°C and t, °C. "t_1 t t_2" denotes that the coefficients apply if t lies between t_1 and t_2. Unit of $Q = 1\mu v/°C = 10^{-6}$ volt/°C; t = centigrade temperature, °C.

Ag-Al; 0° t 100°; Q_{Pb} (18)

Vol. % Ag*	Annealed		Quenched	
	a	b	a	b
0.00	−0.07	−0.02	−0.04	−0.06
4.98	+0.67	−0.22	+0.43	−0.35
10.1	+0.74	−0.16	+0.70	−0.19
20.1	+0.93	+0.32	+1.05	+0.13
30.3	+1.24	+0.63	+1.39	+0.44
39.7	+1.58	+0.68	+1.84	+0.53
50.6	+2.24	+0.81	+2.75	+0.95
56.1	+2.90	+1.15	+3.25	+1.22
58.0	+3.01	+1.20	+3.56	+1.24
60.9†	+3.67	+2.13	+4.03	+1.54
63.5	+2.75	+0.96	+2.88	+0.81
67.4	+1.74	+0.56	+1.80	+0.58
69.8	+1.37	+0.34	+1.53	+0.22
73.2‡	+0.95	+0.37	+1.36	+0.25
75.4	+1.08	+0.40	+1.23	+0.29
80.0	+2.23	+0.55	+2.15	+0.64
90.3	+1.83	+0.35	+1.76	+0.48
95.1	+1.51	+0.47	+1.46	+0.40
100.0	+2.51	+0.76	+2.44	+0.72

* Electrolytic Ag. † Ag_3Al_2. ‡ Ag_3Al.

Ag_3Al_2-$AlCu_3$; 0° t 100°; Q_{Pb} (18)

Vol. % Ag_3Al_2	Annealed		Quenched	
	a	b	a	b
0	−1.36	+0.37	+1.48	+0.77
11.6	−4.18	−0.91	−3.79	+0.11
31.3	+3.71	+2.39	−2.93	+0.31
50.2	+6.94	+1.75	+9.56	+2.47
69.1	+3.99	+1.30	+6.27	+1.82
92.4	+2.78	+1.18	+3.15	+0.97
100.0	+3.67	+2.13	+4.03	+1.54

Ag-Au; 0° t 100°; Q_{Cu} (69)

Wt. % Au	a	b	Wt. % Au	a	b
0	+0.20	0.00	60	−2.13	−1.34
5	−1.34	−0.53	80	−2.16	−0.94
20	−2.70	−0.40	95	−0.84	−0.32
40	−2.40	−1.20	100	−0.00	−0.00

Ag-Cd; 0° t 100°; Q_{Cu} (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	−0.31	+0.04	11.9	−1.41	−0.30
4.0	−1.32	−0.23	16.3	−1.42	−0.38
8.8	−1.42	−0.30	25.7	−1.23	−0.29

Ag-Hg; *see* **Hg**

Ag-Pd; 0° t 900°; Q_{Pt} (39)

Wt. % Ag	a	b	c
0	− 2.61	−0.444	−1.296
10	− 6.89	−2.778	+0.185
20	−11.44	−5.444	+2.037
30	−16.56	−7.444	+3.518
40*	−26.78	−6.667	+3.704
50	−20.333	−4.333	+1.667
60	−10.55	−1.889	−0.926
70	− 4.72	−0.333	−1.481
80	− 1.17	−0.278	−0.278
90	+ 0.22	+2.000	−0.741
100	+ 5.67	+2.667	−0.000

* Ag_2Pd_3.

Ag-Pt; 0° t 900°; Q_{Pt} (39)

Wt. % Pt	a	b	Wt. % Pt	a	b
10	+0.50	+1.00	30	−3.375	−0.938
25	−1.50	−0.624	33	−4.25	−1.00

Ag-Sb; t = 18°; Q_{Cu} (41); error = ±4.5%

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
10	−1.7	29	− 6.8	70	+14.33
15	−1.2	30	− 5.55	80	+17.63
20	−0.91	31	− 4.0	90	+20.5
25	−2.32	35	+ 1.32	95	+22.5
27	−2.9	40	+ 2.98	100	+32.0
27.07	−4.8	50	+ 8.15		
28*	−7.65	60	+12.12		

* Ag_3Sb.

Ag-Sn; 0° t 100°; Q_{Cu} (10); for 4 Wt. % Sn, a = − 8.21, b = +3.39

Ag-Tl; 0° t 100°; Q_{Cu} (10)

Wt. % Tl	a	b	Wt. % Tl	a	b
2.73	+2.95	−0.81	4.76	+12.24	−0.108

Al-Bi; 0° t 100°; Q_{Pb} (18)

Vol. % Bi*	Annealed		Quenched	
	a	b	a	b
0	− 0.07	−0.02	− 0.04	−0.06
1.89	− 0.36	−0.01	− 0.25	−0.05
4.83	− 0.85	−0.12	− 0.46	−0.01
10.0	− 0.92	−0.20	− 0.54	−0.02
30.0	− 9.27	−2.05	− 9.06	−2.09
50.0	−21.9	−2.14	−22.5	−2.14
70.0	−32.6	−3.60	−36.8	−3.36
90.0	−45.7	−0.12	−55.1	−3.02
94.6	−52.7	−1.24	−58.6	−3.48
97.9	−57.8	−1.46	−65.6	−2.01
100.0*	−58.7	−3.26	−55.7	−0.34

* Electrolytic.

Al-Cu; 0° t 100°; Q_{Pb} (18)

Vol. % Cu	Annealed		Quenched	
	a	b	a	b
0	− 0.07	−0.02	− 0.04	−0.06
1.18	+ 0.29	+0.23	+ 0.44	+0.07
2.78	+ 0.37	+0.58	+ 0.62	+0.22
6.41	+ 0.27	+0.45	+ 0.50	+0.15
10.6	+ 0.09	+0.27	+ 0.34	+0.06
16.3	+ 0.03	+0.20	+ 0.12	+0.03
22.1	− 0.24	−0.24	+ 0.06	−0.47
24.1	− 0.20	−0.40	− 0.05	−0.41
26.2*	− 0.28	−0.42	− 0.11	−0.41
31.6	+ 1.44	+0.61	+ 1.32	+0.48
37.9	+ 3.65	+1.38	+ 3.30	+1.26
41.7†	+ 3.80	+1.55	+ 3.96	+1.46
47.3	+ 3.48	+1.32	+ 3.30	+1.14
50.1	+ 2.72	+1.15	+ 2.98	+1.00
51.7‡	+ 2.81	+1.20	+ 2.76	+0.96
52.6	+ 6.64	+1.34	+ 5.83	+1.60
54.4	+11.80	+2.65	+11.25	+2.34
58.8	+ 6.07	+1.00	+ 6.10	+1.58
64.7	− 2.32	+0.23	− 1.22	+0.50
68.3§	− 1.36	+0.37	+ 1.48	+0.77
74.3	+ 1.78	+0.74	+ 2.33	+0.79
80.3	+ 2.06	+0.71	+ 2.27	+0.73
86.0	+ 2.15	+0.68	+ 2.17	+0.69
94.0	+ 2.24	+0.66	+ 2.24	+0.66
100.0	+ 2.88	+0.98	+ 2.88	+0.98

* Al_2Cu. † AlCu. ‡ Al_2Cu_3. § $AlCu_3$.

Al-Cu; 0° t 820°; Q_{Cu}* (64)

Wt. % Cu*	a	b	Wt. % Cu*	a	b
6.0	−2.21	−0.680	94.0	−1.78	−0.040
90.0	−1.21	−0.104	95.0	−2.53	−3.20
92.5	−1.59	−0.090	97.0	−2.31	−3.00

* Electrolytic.

Al-Fe; 0° t 100°; Q_{Pb} (18)

Vol. % Fe*	Annealed		Quenched	
	a	b	a	b
0	−0.07	−0.02	−0.04	−0.06
4.85	−0.65	−0.53	−1.07	−0.39
9.90	−1.46	−1.37	−2.04	−1.26
14.9	−2.13	−2.03	−2.45	−1.90
19.1	−2.65	−3.14	−2.85	−2.86
25.7			−4.17	−1.98

* Swedish Fe; 0.08 % C.

Al-Mg; 0° t 100°; Q_{Pb} (18)

Vol. % Mg*	Annealed		Quenched	
	a	b	a	b
0.0	−0.07	−0.02	−0.04	−0.06
5.68	+0.84	−0.39	+1.04	−0.59
10.28	+1.12	−0.58	+1.11	−0.58
20.7	+0.85	−0.55	+0.91	−0.58
25.4	+0.72	−0.70	+0.75	−0.56
30.3	+0.21	−0.42	+0.25	−0.37
39.5	−0.40	−0.40	−0.82	−0.28
41.2	−0.42	−0.55	−0.76	−0.43
46.0	−0.56	−0.60	−1.36	−0.37
51.7	−0.95	−0.82	−2.49	−0.56
58.5†	−4.19	−1.08	−4.56	−0.88
62.8	+1.68	−1.53	+1.57	−1.50
64.3	+3.51	−1.18	+3.48	−0.99
65.3	+3.53	+0.86	+3.43	+0.60
67.8‡	+1.22	+0.30	+1.01	+0.36
70.1	−0.05	+0.10	−0.13	+0.23
73.9	−0.33	+0.09	−0.99	−0.02
80.7	−0.78	−0.05	−1.52	−0.16
89.9	−1.64	−0.18	−1.86	−0.22
95.3	−1.64	−0.18	−1.46	−0.55
100.0	+0.18	−1.02	+0.24	−0.83

* 99.2 % Mg, 0.3 % Fe, 0.5 % Si by Wt. † AlMg. ‡ Al_2Mg_3.

Al*-Mg;† 0° t 420°; Q_{Cu} (60)

Wt. % Al*	a	b	c
0	−2.656	−0.7082	
10‡	−6.423	+1.196	− 4.961
87.5‡	−2.057	−0.7871	
90‡	−1.780	−0.980	
90‡§	−2.132	−0.836	
100‖	−4.495	+2.408	−12.877

* 99.67 % Al, 0.16 % Si, 0.15 % Fe, 0.02 % Cu. † Pure Mg. ‡ Cold-drawn. § Contains 8 % Mg and 2 % Ni. ‖ Heated red-hot and cooled in air.

Al-Mn; 0° t 100°; Q_{Pb} (18)

Vol. % Mn*	Annealed		Quenched	
	a	b	a	b
0.0	− 0.07	−0.02	−0.04	−0.06
2.40	− 5.04	−0.46	−5.17	−0.80
5.01	− 4.93	−0.91	−4.68	−0.97
8.99	− 4.81	−0.71	−4.62	−1.12
15.1	− 4.53	−0.58	−4.47	−1.08
19.8†	− 0.56	−1.48	−1.62	−1.66
24.1	+27.3	+2.59	+3.44	−0.21

* 96.8 % Mn, 1.8 % Al, 0.9 % Si, 0.5 % Fe, by Wt. In computing Vol. % of alloy, an allowance was made for the Al in the Mn. † Al_3Mn.

Al-Ni; 0° t 100°; Q_{Pb} (18)

Vol. % Ni*	Annealed		Quenched	
	a	b	a	b
3.81	− 0.56	−0.07	− 0.50	−0.10
8.12	− 0.75	−0.10	− 0.68	−0.27
11.7	− 1.30	−0.15	− 1.21	−0.32
18.4†	− 1.35	−0.22	− 0.83	−0.73
19.8	− 0.91	−0.36	− 0.80	−0.76
60.7	− 0.93	−0.31	− 4.57	−3.39
66.4	+ 6.02	+0.39	+ 6.07	−0.05
70.3	+10.4	−0.24	+10.3	−0.45
79.3	− 5.30	−1.39	− 4.93	−3.50
90.0	−17.3	−4.94	−14.9	−7.98
94.9	−16.8	−5.62	−16.9	−6.96
100.0	−16.2	−5.95	−16.2	−5.95

* No trace of Fe. † Al_3Ni.

Al-Ni; 0° t 1200°; Q_{Pt} (68)

Wt. % Al	a	b
5	−5.671	−0.6218

Al-Pb; 0° t 200°; Q_{Cu} (64)

Wt. % Al	a	b	Wt. % Al	a	b
0	−2.58	+0.02	96.0	−1.25	−1.00
92.0	−1.19	+0.07	100.0	−1.62	−0.59
94.0	−1.41	+0.06			

Al-Sb; 0° t 400°; Q_{Cu} (64)

Wt. % Sb	a	b	c
0.0	− 1.030	−2.243	+ 8.665
60.0	− 0.816	−0.598	+ 2.607
62.0	− 0.233	−0.726	+ 2.492
65.0	− 0.781	−0.968	+ 3.626
70.0	− 0.306	−1.083	+ 3.715
100.0	−34.50	−4.941	+48.38

Al-Sn;* 0° t 100°; Q_{Pb} (18)

Vol. % Sn	Annealed		Quenched	
	a	b	a	b
5.03	−0.40	+0.25	−0.34	+0.46
10.1	−0.41	+0.23	−0.47	+0.48
19.9	−0.51	+0.38	−0.54	+0.54
29.2	−0.54	+0.53	−0.60	+0.66
40.2	−0.54	+0.53	−0.51	+0.64
49.8	−0.54	+0.56	−0.50	+0.64
51.4	−0.51	+0.48	−0.45	+0.55
59.4	−0.52	+0.54	−0.43	+0.61
62.0	−0.36	+0.45	−0.45	+0.55
69.8	−0.47	+0.48	−0.38	+0.61
80.0	−0.30	+0.53	−0.28	+0.58
90.5	−0.17	+0.48	−0.18	+0.53
95.0	−0.14	+0.42	−0.14	+0.42
100.0	−0.14	+0.42	−0.14	+0.42

* Al is soluble in Sn in all proportions.

Al*-Zn;† 0° t 100°; Q_{Pb} (18)

Vol. % Zn	Annealed		Quenched	
	a	b	a	b
4.60	+0.41	+0.07	+0.55	+0.29
9.50	+0.53	+0.32	+0.78	+0.40
19.3	+0.71	+0.44	+0.88	+0.47
29.0	+0.98	+0.52	+1.01	+0.58
39.3	+1.19	+0.66	+1.17	+0.69
49.6	+1.40	+1.00	+1.43	+1.04
60.0	+1.56	+1.05	+1.64	+1.13

Al-Zn.—*(Continued)*

Vol. % Zn	Annealed		Quenched	
	a	b	a	b
68.7	+1.68	+1.20	+1.83	+1.30
78.4	+1.83	+1.26	+1.85	+1.31
89.0	+2.02	+1.54	+2.13	+1.50
95.0	+2.09	+1.69	+2.60	+1.56
100.0	+1.84	+1.59	+1.62	+1.36

* 99.7 % Al, 0.1 % Fe, 0.2 % Si, by Wt.
† Al is soluble in Zn in all proportions.

Au-Cd; 0° t 100°; Q_{Cu} (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	−0.17	−0.03	8.7	−1.81	−0.50
5.4	−1.52	−0.19	17.2	−2.39	−0.48

Au-Cu; 0° t 150°; Q_{Cu} (69)

Wt. % Cu	a	b	Wt. % Cu	a	b
10.0	−0.40	−0.80	60.0	−0.83	−0.80
20.0	−0.84	−0.82	80.0	−0.59	−0.68
40.0	−0.88	−0.78	95.0	+0.25	−0.70

Au-Pd; 0° t 1000°; Q_{Pt} (39)

Wt. % Au	a	b	c
10.0	− 7.944	−1.111	−0.185
20.0	−11.722	−1.556	+0.185
30.0	−12.722	−3.111	+1.296
40.0	−14.333	−5.222	+2.778
50.0	−21.777	−5.556	+3.704
60.0*	−26.444	−6.778	+5.370
70.0	−26.000	−0.444	−1.111
80.0	− 4.111	−1.000	−0.185
90.0	− 1.000	+1.000	−0.556
100.0	+ 6.777	+2.556	−0.926

* AuPd.

Au-Pt; Q_{Pt} is negative and on repeated or continued heating increases continually in absolute value, not becoming constant even after 2 hr at 900°C; its absolute value increases with the Pt content (39).

Au-Sb; t = 18°; Q_{Cu} (41)

Wt. % Sb	50	55*	60
Q_{Cu} (18°)	−1.07	−17.0	−0.31

* $AuSb_2$.

Au-Zn; 0° t 100°; Q_{Cu} (71)

At. % Zn	a	b	At. % Zn	a	b
0.0	−0.17	−0.03	10.1	−2.25	−0.53
4.9	−1.85	−0.01	18.3	+0.33	+0.58

Bi-Cd; 0° t 125°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	−105.50	+54.00	40.0	−31.04	+15.08
5.0	− 77.50	+39.60	70.0	−12.34	+ 5.08
10.0	− 68.27	+37.34	90.0	− 5.47	+ 2.14
25.0	− 47.13	+25.06	100.0	+ 1.56	+ 0.48

Bi-Hg; *see* **Hg**

Bi-Pb; t_1 t t_2; E_{Cu} (28)

Wt. % Pb	t_1	t_2	a	b	d
10.0	0	200	− 8.25	−15.50	0
	241	450	−17.05	+ 3.30	−2000
20.0	0	110	+ 2.50	0.00	0
	110	200	−11.50	−17.0	0
	200	450	0	− 1.50	−1000
30.0	0	120	+10.00	0.00	0
	126	450	− 2.083	− 0.834	+1250

Bi-Pb.—(*Continued*)

Wt. % Pb	t_1	t_2	a	b	d
40.0	0	110	+ 2.50	0.00	0
	110	450	− 6.365	+ 0.230	+1000
50.0	0	450	− 1.975	− 0.825	0
60.0	0	450	− 2.750	− 0.750	0

Bi-Pb; 0° t 150°; Q_{Pb} (6)

Vol. % Bi	a	b	Vol. % Bi	a	b
5.5	−0.0	+0.50	91.5	+ 2.00	−1.00
12.0	−0.0	+0.50	94.5	+ 0.50	−0.50
22.5	−0.30	+1.00	100.0	−30.00	−5.00
82.5	+2.50	−1.00			

Bi-Sb; t = 18°; Q_{Cu} (41)

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
2.0	−71.5	30.0	−42.0	70.0	+ 7.55
5.0	−74.7	40.0	−19.0	80.0	+15.5
10.0	−77.7	50.0	−11.0	85.0	+18.0
15.0	−63.7	55.0	− 3.8	90.0	+23.5
20.0	−53.3	60.0	− 1.95	95.0	+26.7

Bi-Sb; Q_{Cu} (38)

t =	−190°C	−77°C	0°C	+100°C
Wt. % Sb	Q_{Cu}			
0	− 30	− 75	−72	−64
9	−153	−103	−87	−77
11	−156	− 98	−84	−74
13	−130	− 95	−83	−73
20	−110	− 83	−71	−60
50	− 15	− 21	−21	−14
70	+ 3.4	+ 6.3	+ 8.6	+13
100	+ 12	+ 29	+36	+45

Bi-Sn; 0° t 100°; Q_{Cu} (24)

Wt. % Sn	a	b	Wt. % Sn	a	b
0.0	−40.20	−50.0	3.72	+29.4	−24.0
1.0	+ 6.77	−33.5	6.36	+39.4	−26.0
2.0	+26.0	−46.5	9.93	Q = +38.0 if t = 20.7°	

Bi-Sn; t_1 t t_2; E_{Cu} (28)

Wt. % Sn	t_1 = 0, t_2 = 130	t_1 = 150, t_2 = 450	
	a	a	d
10	+32.4*	−4†	+5300†
20	+27.6	−2.39‡	+4300‡
30	+18.0	−3.38	+2790
40	+13.35	−3.79§	+2190§
50	+10.0	−3.38	+1770
60	+ 3.75	−0.0042	+ 420
70	+ 1.80	−0.00518	+ 270

* t_2 = 125. † t_1 = 200. ‡ t_1 = 210. § t_1 = 130.

Bi-Sn; t = 30.7°; Q_{Pb} (48)

Wt. % Bi	Q_{Pb}	Wt. % Bi	Q_{Pb}	Wt. % Bi	Q_{Pb}
50.0	+ 8.75	90.0	+45.09	99.25	+12.96
60.0	+12.55	95.0	+45.62	99.62	+ 0.41
70.0	+20.14	97.5	+41.34	100.0	−64.66
80.0	+28.26	98.75	+33.48		

Bi-Te; t = 18°; Q_{Cu} (41)

Wt. % Bi	Q_{Cu}	Wt. % Bi	Q_{Cu}	Wt. % Bi	Q_{Cu}
2.0	+127.0	35.0	− 77.3	53.0	+62.0
5.0	+ 71.1	40.0	− 90.1	55.0	+27.7
10.0	+ 58.4	42.0	− 99.0	60.0	−18.3
13.9	+ 33.0	45.0	− 89.0	70.0	−21.8
15.0	+ 20.0	49.0	− 36.0	80.0	−16.2
20.0	− 9.83	50.0	+ 52.0	85.0	−11.0
25.0	− 37.0	52.0	+ 93.3	95.0	− 3.5
30.0	− 54.0	52.14*	+121.8	100.0	−57.4

* Bi_2Te_3.

Cd-Hg; 0° t 100°; Q_{Cu} (10); *see also* Hg-Metal

Wt. % Hg	a	b	Wt. % Hg	a	b
5.14	−4.33	+5.16	10.0	−3.62	+5.65

Cd-Pb; 0° t 100°; Q_{Pb} (6)

Vol. % Cd	8.0	15.0	73.8	85.0
a	+1.05	+1.75	+2.10	+2.60
b	+2.9	+3.4	+4.1	+3.9

Cd-Sb; 0° t 150°; Q_{Pb} (6)

Vol. % Sb	a	b	Vol. % Sb	a	b
6.6	+ 5.0	+ 4.0	58.5	+235.0	+48.0
25.8	+20.0	+13.0	66.5	+420.0	+63.0
41.0	+70.0	+19.0	72.0	+235.0	+46.0

Cd-Sb; Q_{Cu}*

Wt. % Sb	18°C (41)	50°C (8)	Wt. % Sb	18°C (41)	50°C (8)
	Q_{Cu}			Q_{Cu}	
0	+0.38		51.7	+305.0	
33.3		+ 4.48	66.7		+87.20
50.0		+134.2	100	+ 32.0	

* For 50 atom %, Q_{Cu} varies rapidly with composition and is much affected by unhomogeneous structure; mean value between 18 and 55°C may amount to +543 (35, 35.1).

Cd-Sn; 0° t 150°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	−2.73	−1.34	70.0	−0.30	+1.60
10.0	−2.60	−0.34	90.0	−0.40	+3.20
30.0	−1.66	−0.28	100.0	−0.06	+3.72
50.0	−1.33	+1.06			

Cd-Zn; 0° t 150°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	+0.20	0.00	70.0	−0.56	+4.04
10.0	−0.267	+0.53	90.0	−0.63	+4.22
30.0	−0.99	+2.58	100.0	−0.06	+3.72
50.0	−0.54	+2.68			

Co-Cu; t = 50°; Q_{Cu} (66)

Wt. % Co	Q_{Cu}	Wt. % Co	Q_{Cu}	Wt. % Co	Q_{Cu}
1.5*	+30.8	13.9	+29.1	70.3	+18.5
1.9	+32.1	23.6	+26.5	80.5	+17.6
3.1	+33.0	34.4	+25.9	90.4	+16.7
4.1*	+32.1	46.6	+20.8	100*	+27.37
6.7	+31.5	59.4†	+19.4		

All alloys contain traces of Fe and Ni. Q was measured after heating to 160°C.

* For 0° t 100°:

Co	1.5	4.1	100 %
a	+30.52	+31.03	+23.24
b	+0.776	+0.416	+ 8.26

† Contains 0.6% Fe.

Co-Fe; *see* Fe alloys

Co-Ni; 0° *t* 1200°; Q_{Pt} (68)

Wt. % Co	a	b	c
10	−28.39	+9.944	−6.546

Cr-Fe; *see* Fe alloys

Cr-Ni; 0° *t* 1200°; E_{Pt} (68)

Wt. % Cr	a	b	c
4.0	+22.43	+1.531	−1.914
5.0	+21.304	+1.716	−4.038
8.0	+28.47	+1.325	−1.492
10.0	+30.3	0.0	0.0
12.0	+19.9*	+2.8	
12.0	+31.28†	d = −1700	
16	+11.00‡	+7.70	−8.655
16	+30.22§	d = −3830	

* 0° *t* 200°. † 200° *t* 1200°. ‡ 0° *t* 600°. § 600° *t* 1200°

Cu-Hg; *see* Hg

Cu-Mn-Ni; 0° *t* 100°; E_{Pb} (17) manganin (84Cu, 12Mn, 4Ni) (?); a = +1.366, b = +0.0828, c = +3.36.

Cu-Mn-Ni-Fe;* *t* = 25°; Q_{Cu} (47)

Wt. %				*Q*
Cu	Mn	Ni	Fe	
88.02	9.93	1.71	0.24	+4
87.24	10.26	1.77	0.52	+5
88.20	8.84	1.78	0.93	+3
83.60	12.03	3.41	1.04	+8
84.72	12.83	2.08	0.73	+4

* All specimens annealed.

Cu-Ni; 0° *t* 100°; Q_{Cu} (71)

At. % Ni	a	b	At. % Ni	a	b
5.4	−17.67	−4.55	66.4	−32.12	−2.47
10.8	−22.42	−6.69	69.6	−32.76	−1.58
21.4	−28.11	−7.73	73.0	−34.02	−1.48
32.1	−32.93	−7.71	74.5	−33.01	−0.71
41.9	−35.10	−7.74	74.7	−30.43	−2.36
50.9	−39.41	−8.66	82.8	−33.65	−1.66
55.1	−33.17	−6.75	88.3	−31.08	−3.84
62.8	−32.56	−5.95	100.0	−25.56	−3.40

For 3.94 Wt. % Ni, a = −15.14, b = +10.2; for 17.3 Wt. % Ni, a = −24.9, b = −13.2 (10).

Constantan = 60% Cu, 40% Ni; 0° *t* 400°, a = −38.105, b = −8.884, c = +8.568; error in *E* = ±1% (2).

Cu-Ni; t_1 *t* t_2; E_{Pt} (68)

Wt. % Cu	t_1	t_2	a	b	c
0.0	0	1200	−17.12	+2.460	−2.193
10.0	0	400	−30.85	+4.250	
	400	1200	−21.71		
30.0	0	300	−36.87	+4.712	
	300	1200	−39.37	d = +2980	
50.0	0	350	−53.23	+4.756	
	350	1200	−50.64	d = +1700	
70.0	0	400	−44.73	−0.978	
	400	1200	−49.80		

Cu-Ni; *t* = 50°; Q_{Pb} (34)

Wt. % Ni	Q_{Pb}	Wt. % Ni	Q_{Pb}	Wt. % Ni	Q_{Pb}
10.0	−22.0	41.8	−38.8	62.8	−31.5
15.5	−27.3	46.0	−38.8	89.3	−25.1
20.0	−29.0	49.0	−35.4	93.5	−23.0
24.5	−29.4	50.7	−35.8	100.0	−20.2
30.0	−33.3	56.0	−34.2		

Cu-Ni-Zn; −200° *t* +100°; E_{Pb}, German silver (commercial) (31); a = −10.861, b = −3.294, c = +1.893.

Cu-P; *t* = 18°; Q_{Cu} (41)

Wt. % P	Q_{Cu}	Wt. % P	Q_{Cu}	Wt. % P	Q_{Cu}
1.88	+0.06	6.20	+1.40	13.97	+6.30
4.03	+0.435	8.75	+2.10	14.16*	+6.85
4.08	+0.48	12.70	+5.20	14.29	+4.30
5.75	+1.30	13.62	+6.00	14.56	+4.00

* Cu_3P.

Cu-Sn; −80° *t* 100°; Q_{Pb} (56)

Vol. % Sn	a	b	Vol. % Sn	a	b
0	+3.57	+1.01	55	+2.07	+0.80
5	+0.81	+0.20	60	+2.43	+0.76
10	+0.66	+0.21	65	+2.45	+0.70
15	+1.17	+0.12	70	+1.30	+0.68
20	+1.25	+0.23	75	+1.47	+0.66
25	+0.86	+0.28	80	+1.06	+0.70
30	+0.49	+0.37	85	+0.41	+0.46
35	+2.13	+0.39	90	+0.31	+0.46
40	+1.54	+0.73	95	−0.10	+0.185
45	+1.58	+0.89	100	−0.13	+0.25
50	+2.18	+0.89			

Cu-Sn; 0° *t* 100°; Q_{Cu}; for 5 Wt. % Sn, a = −3.46, b = +0.322 (10).

Cu-Zn;* −78° *t* 100°; Q_{Pb} (61)

Vol. % Zn	a	b	Vol. % Zn	a	b
0.0	+2.350	+1.38	59.5†	−0.062	+0.40
3.15	+0.707	+1.01	63.2	−1.082	+0.79
9.3	+0.608	+0.81	68.4	+0.639	+2.20
14.2	+0.710	+0.56	73.6‡	+3.330	+2.45
18.15	+0.740	+0.50	79.3	+2.195	+1.36
22.8	+0.702	+0.39	80.15	+1.407	+0.97
31.5	+0.602	+0.59	85.5	+1.821	+1.13
33.7	+0.699	+0.69	90.4§	+4.716	+1.75
39.3	+0.602	+0.59	93.7	+4.279	+1.54
41.7	+0.249	+0.60	95.0	+4.288	+1.72
47.7	+0.476	+0.44	98.8	+3.220	+1.69
53.2	+0.490	+0.62	100.0	+2.609	+1.49
53.4	+0.539	+0.73			

* Electrolytic Cu; Zn free of As and Pb. † CuZn. ‡ $CuZn_2$. § $CuZn_6$.

Alloys of less than 45% Zn were annealed for 36 hr at temperature about 30° below transformation point; other alloys annealed at 650°C.

Cu-Zn; 0° *t* 100°; E_{Pb}, brass (commercial) a = +0.140, b = +0.5166 (59).

Fe-C Steel; *see* Tables 4, 5

Fe-Co;* *t* = 100°; E_{Cu} (37)

Wt. % Co	10.0	20.0	30.0
E_{Cu}	− 0.64	− 3.70	− 3.50

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr;* *t* = 100°; E_{Cu} (37); *see also* Table 4

Wt. % Cr	E_{Cu}	Wt. % Cr	E_{Cu}	Wt. % Cr	E_{Cu}
10.0	+1.20	20.0	+0.43	29.5	+0.31
18.0	+1.04	23.5	+0.32		

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Ni;* t = 100°; E_{Cu} (37)

Wt. %				E_{Cu}
Cr	Ni	Si	C	
4.0	17.0	0	0	−0.12
10.0	20.0	0	0	−0.46
10.0	55.0	0	0	0.00
15.0	60.0	0	0	+0.07
20.0	55.0	0	0	+0.07
25.0	55.0	0	0	−0.08
7.0	75.5	0.03	0.22	+0.20
13.1	70.6	0.02	0.17	+0.20
13.1	70.6	0.02	0.20	+0.17
11.0	84.0	0.40	0.034	+1.49
15.6	80.4	0.58	0.23	+0.76

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni;* t = 100°; E_{Cu} (37)

Wt. %					E_{Cu}
Cr	Mn	Ni	Si	C	
0.31	6.6	58.3	1.0	0.16	−0.94
0.11	12.0	82.8	1.058	0.068	−1.11
0.11	6.2	88.5	0.061	0.065	−1.60
31.9	0.20	57.7	0.30	0.40	−0.08
22.7	0.30	69.0	0.25	0.20	+0.24

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni; t_1 t t_2; E_{Pt} (60) nichrome (16Cr, 22.5Fe, 3Mn, 58.5Ni approximately)

t_1	t_2	a	d	t_1	t_2	a	d
0	420	+25.0		500	1082	−34.9	+6994

Fe-Mn; *see* Table 4

Fe-Mn-Ni;* t = 100°; E_{Cu} (37)

Wt. %		E_{Cu}	Wt. %		E_{Cu}
Mn	Ni		Mn	Ni	
3.0	10.0	−1.09	6.0	17.5	−0.73
2.0	12.0	−1.02	2.0	22.0	−1.84
2.0	17.0	−1.50	6.0	44.0	−0.59
3.0	17.0	−0.79			

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Mo; *see* Table 4

Fe-Ni;* t = 100°; E_{Cu}(37); *see also* Table 4

Wt. %			E_{Cu}	Wt. %			E_{Cu}
Ni	Si	C		Ni	Si	C	
0	0	0	+0.86	81.2	0.014	0.19	−2.45
17.0	0	0	−0.64	93.0	0	0	−1.90
20.0	0	0	−0.55	94.6	0.64	0.11	−1.40
30.0	0	0	−0.52	96.3	0.35	0.12	−2.00
33.5	0.16	0.25	−0.48	100.0	0	0	−2.38

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Ni; t = 48°; Q_{Cu} (49)

Wt. % Ni	Q_{Cu}*	Wt. % Ni	Q_{Cu}*	Wt. % Ni	Q_{Cu}*
4.0	+ 2.32	21.0	+23.5	45.0	+29.0
7.0	+ 7.32	22.11	+21.0	47.08	+31.9
13.0	+16.9	26.4	+16.7	90.0	+17.9
14.0	+17.2	35.09	+ 9.79		
18.0	+21.0	40.0	+22.4		

* If diameter of wire > 0.12 cm, Q is somewhat greater.

Fe-Ni; t_1 t t_2; E_{Pt} (68)

Wt. % Fe	t_1	t_2	a	b
10	0	750	−27.66	+7.326
	750	1200	+20.612*	

* d = −15 600.

Fe-Si; *see* Table 4

Fe-Ti; at 50°C, Q_{Cu} = −140 (52)

Fe-W; *see* Table 4

Hg-Metal; 20° and t; E_{Hg} (33)

Metal	At.*	80°	100°	180°
Ag	1	+ 1.0	+ 1.2	+ 2.6
Bi	1	+ 59.6	+ 84.5	+203.6
Cd†	1	+ 7.9	+ 12.1	+ 28.2
Cu	1	+ 0.7	+ 0.8	+ 1.3
K	1	− 21.6	− 33.0	− 82.2
	8.47	−177.2	−273.4	−694.0
Li	0.253	− 13.9	− 22.4	− 43.4
	1	− 55.4	− 78.7	−184.8
Na	1	− 37.5	− 51.7	−117.1
	3.34	−114.2	−160.7	−389.0
Pb‡	1	+ 25.6	+ 34.6	+ 82.5
Sb	1	+ 5.1	+ 7.5	+ 21.4
Sn	1	+ 19.9	+ 26.9	+ 65.8
Tl‡	1	− 41.8	− 57.6	−138.8
Zn	1	+ 6.2	+ 9.2	+ 24.4

* Atoms of metal per 100 atoms of Hg. † *See* Cd-Hg for Q_{Cu}. ‡ *v. infra.*

Hg-Pb; 20° and t; E_{Hg} (33)

Wt. Pb*	80°	100°	180°
	E_{Hg}		
1.03	+ 25.6	+ 34.6	+ 82.5
2.06	+ 35.5	+ 48.9	+110.1
3.09	+ 70.8	+120.8	+239.9
6.19	+ 92.0	+154.0	+548.3
9.28	+124.3	+162.6	+629.2
12.38	+ 94.2	+151.4	+529.9
15.47	+ 87.3	+148.2	+439.5
18.57	+ 96.6	+170.9	
24.77	+113.5	+179.6	+591.0
49.53	+147.2	+217.2	+656.9
98.2	+169.4	+250.3	+733.2
206	+216.5	+280.6	+746.7

* Grams Pb per 100 g Hg.; *see also* Hg-Metal.

Hg-Tl; 20° and t; E_{Hg} (33)

Wt. Tl*	80°	100°	180°
	E_{Hg}		
0.255	− 10.8	− 14.6	− 32.5
0.51	− 21.8	− 29.8	− 68.8
1.02	− 41.8	− 57.6	− 138.8
2.04	− 67.9	− 93.2	− 199.2
3.055	− 79.3	−111.0	− 250
4.08	− 86.6	−125.8	− 282.1
6.11	− 82.7	−114.3	− 246.8
12.22	− 44.4	− 65.3	− 120.7
24.44	+ 35.8	+ 52.2	+ 149.8
∞ †	+321.7	+445.0	+1001.1

* Grams Tl per 100 g Hg; *see also* Hg-Metal. † Pure Tl.

Ir-Pt;* 0° t 1200°; Q_{Pt} (39)

Wt. % Ir	a	b	c
5	+10.375	+0.250	−0.2344
10	+13.208	+0.750	−0.3906
15	+14.083	+1.063	−0.3906
20	+13.00	+1.875	−0.9375
25	+11.250	+2.250	−1.1718
30	+10.75	+2.375	−0.9375
35	+10.50	+2.375	−0.9375

* Alloy in all proportions.

Mn-Ni; t_1 t t_2; E_{Pt} (68); Wt. % Mn = 5

t_1	t_2	a	b
0	400	−2.158	+6.58
400	1200	−0.375	d = −3220

Mo-Ni; 0° t 1200°; Q_{Pt} (68)

Wt. % Mo	a	b	Wt. % Mo	a	b
4	+11.85	+1.2056	12	+27.45	+1.788
5	+14.90	+1.48	16	+27.45	+2.00
8	+21.08	+1.784	20	+23.38	+2.392
10	+24.70	+1.720			

Nichrome; *see* **Fe-Cr-Mn-Ni**

Ni-Ta; 150° t 1200°; E_{Pt} (68); for 5 Wt. % Ta, a = −0.573, d = −1914

Ni-Ti; t_1 t t_2; E_{Pt}; Wt. % Ti = 5 (68)

t_1	t_2	a	b
0	600	−7.98	+1.256
600	1200	−1.117	d = −1860

Ni-V; 0° t 1200°; Q_{Pt} (68)

Wt. % V	a	b	Wt. % V	a	b
5	+18.30	+1.72	10	+26.5	+1.56

Ni-W; 0° t 1200°; Q_{Pt} (68)

Wt. % W	a	b	Wt. % W	a	b
4	+1.428	+0.885	12	+12.26	+1.906
5	+2.90	+1.08	16	+16.38	+1.96
8	+6.91	+1.664	20	+20.22	+2.128
10	+9.70	+1.72			

Ni-Zr; 0° t 1200°; Q_{Pt} (68); for 5 Wt. % Zr, a = −12.57, b = +2.286

Pb-Sb; 0° t 150°; Q_{Cu} (69)

Wt. % Sb	a	b	Wt. % Sb	a	b
0.0	−2.83	−0.94	50.0	+ 2.11	+2.08
5.0	−1.68	−1.10	70.0	+ 2.15	+3.80
13.0	−1.54	−0.44	90.0	+ 4.23	+6.54
30.0	+0.33	+1.34	100.0	+37.53	+7.74

Pb-Sn; 0° t 150°; Q_{Cu} (69)

Wt. % Sn	a	b	Wt. % Sn	a	b
0	−2.83	−0.94	50	−2.67	−1.06
5	−2.63	−0.94	80	−3.13	−0.54
30	−2.80	−0.80	100	−2.73	−1.34

Pb-Tl; 0° t 180°; Q_{Pb} (33); for 2.03 Wt. % Tl, a = −0.0120, b = −0.0742

Pb-Zn; 0° t 180°; Q_{Pb} (33); for 0.63 Wt. % Zn, a = +0.0040, b = +0.016

Pd-Pt;* 0° t 1200°; Q_{Pt} (39)

Wt. % Pt	a	b	c
0	−3.875	−1.350	−0.234
10	+4.042	−0.563	−0.781
20	+6.792	+0.438	−1.250
30	+7.583	+0.938	−0.885
40	+7.000	+1.375	−0.938
50	+7.167	+1.188	−0.677
60	+5.833	+1.500	−0.729
70	+5.125	+1.135	−0.469
80	+4.875	+0.812	−0.469
90	+3.625	+0.395	−0.234

* Alloy in all proportions.

Pt-Rh; 0° t 1600° Q_{Pt}; *see also* Vol. I, p. 57; error in E_{Pt} may amount to ±50

Wt. % Rh	a	b	c	Lit.
1	+2.19	−0.044	+0.024	(29)
5	+5.99	+0.200	−0.060	(29)
10	+7.013	+0.640	−0.1932	(29)
10*	+7.048	+0.5896	−0.1284	(80)
15	+6.69	+1.072	−0.3276	(29)
20	+6.083	+1.380	−0.3999	(29)
30	+6.12	+1.344	−0.1092	(46)
40	+6.44	+1.344	−0.0468	(46)
100	+6.27	+1.612	−0.1797	(45)

* Le Chatelier's couple.

Pt-Rh; t_1 t t_2; E_{Pt}; Rh, Wt. % = 10; error in E may amount to ±50

t_1	t_2	a	b	c	Lit.
−253	0	+5.97	+4.28		(80)
0	+650	+5.543	+1.804	−1.965	(80)
+650	1600	+8.162	+0.338	d = −283.5	(80)
+250	1600	+8.048	+0.344	d = −310	(45)
+400	1100	+8.259*	+0.3332	d = −313.8	(21)

* Made by Heraeus; diameter = 0.4 mm.

Pt-Ru; 250° t 1500°; E_{Pt} ±5 (45); for 10 Wt. % Ru, a = +9.260; b = +0.300, d = −359

Sb-Sn; t = 30.1°; Q_{Pb} (48)

Wt. % Sb	Q_{Pb}	Wt. % Sb	Q_{Pb}	Wt. % Sb	Q_{Pb}
20	+1.07	60	+12.54	90	+ 7.77
30	+2.16	70	+12.20	95	+ 7.93
50	+6.14	80	+14.08	100	+32.67

Sb-Te; t = 18°; Q_{Cu} (41)

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
2	+139.0	35	+62.3	70	+ 2.3
5	+105.0	38.90*	+82	75	+ 1.6
10	+ 93.0	40	+34.0	80	+ 1.0
13	+ 86.5	45	+13.5	83	+ 3.5
15	+ 81.7	50	+ 9.3	90	+ 6.5
20	+ 74.0	55	+ 8.0	95	+10.0
25	+ 63.0	60	+ 4.5		
30	+ 61.2	65	+ 3.0		

* Sb_2Te_3.

SeSn; E_{Pt} is of same order of magnitude as for Se_2Sn but is of opposite sign (65)

Se_2Sn; 0° t 650°; E_{Pt} (1 ± 0.025); a = +389.5, b = +6.334 (65)

Se-Te; t = 18°; Q_{Cu} (1 ± 0.03) (41)

Wt. % Se	Q_{Cu}	Wt. % Se	Q_{Cu}	Wt. % Se	Q_{Cu}
2.0	+480	15	+680	40	+620
5	+570	20	+580	45	+580
10	+563	30	+540	50	+460

Sn-Te; t = 18°; Q_{Cu} (41)

Wt. % Sn	Q_{Cu}	Wt. % Sn	Q_{Cu}	Wt. % Sn	Q_{Cu}
10	+116.0	45	+22.3	70	−0.2
15	+ 84.0	48.28*	+26.0	80	−0.8
20	+ 71.0	49	+99.0	85	−1.35
30	+ 42.2	50	+ 6.3	90	−1.5
35	+ 34.0	55	+ 1.6	95	−1.4
40	+ 28.0	60	+ 0.7	100	−2.25

* SnTe.

Sn-Zn; 0° t 150°; Q_{Cu} (69)

Wt. % Sn	a	b	Wt. % Sn	a	b
0	+0.20	0.0	70	−1.43	−0.94
10	−0.23	−0.14	90	−2.37	−0.66
30	−1.39	+0.18	95	−2.57	−0.66
50	−1.23	−0.46	100	−2.73	−1.34

Commercial Alloys and Miscellaneous Mixtures

"Akkumulatorenlot" (75Pb, 20Hg, 5Sb), 0° t 300°, $E_{Constantan}$ = 4.18 t (25)

Brass; *see* **Cu-Zn**

Chronin (80)

t, °C	− 78.5	− 170.3	− 188.8	− 252.7
E_{Pb}	+1277	+2435	+2612	+3025

Constantan; *see* **Cu-Ni**

Culmitz (80)

t, °C	E_{Pb}	t, °C	E_{Pb}
− 78.4	+204	−192.6	+401*
	+160*	−252.7	+596
−192.6	+476		+472*

* After annealing.

German Silver; *see* **Cu-Ni-Zn**

Kruppin (80)

t, °C	− 78.5	−170.3	− 188.8	−252.7
E_{Pb}	−280	−992	−1129	−920

Manganin; *see* **Cu-Mn-Ni**

Nernst filament; 980° t 1425°; Q_{Pt}; a = +405 (72)

Nichrome; *see* **Fe-Cr-Mn-Ni**

Nickelin (80)

t, °C	E_{Pb}	t	E_{Pb}
− 78.4	−1256	−192.6	−2416*
	−1259*	−252.7	−2650
−192.6	−2406		−2600*

* After annealing.

Piano wire; *see* Table 4

Platinoid; −200° t 100°; E_{Pb}; a = −10.620, b = −2.766, c = +3.171 (31)

Resistin (80)

t, °C	− 78.5	−170.3	−188.8	−252.7
E_{Pb}	+331	+652	+713	+895

Steel; *see* **Al-Fe, Fe,** and Tables 4, 5

TABLE 4.—MEAN THERMOELECTRIC POWER (E/t) BETWEEN 0 AND t°: STEELS, t = −78.5 AND +100° (32)

For other alloys of Fe, *see* Tables 3, 5. $E = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5}$; $Q = a + bt(10)^{-2} + ct^2(10)^{-5}$. An. = annealed; Qu. = quenched; "t_1 t t_2" denotes that t lies between t_1 and t_2. Except where the contrary is indicated, one junction is at 0°C and the other at t, °C. Steels of low C content were annealed in magnesia; those of about 0.8% C, in turnings of pig iron. Mean error in all cases = *ca.* 30μv(= 30 microvolt). Unit of E = 1μv = 10^{-6} volt; of Q and E/t = 1μv/°C = 10^{-6} volt per 1°C; t = centigrade temperature, °C.

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Al	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
	Al steels; *see also* Table 3; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*											
1A2	0.17	Tr.	0.008	0.022	Tr.	2.04	− 7.65	−12.65	− 8.26	−11.50		
1A3	0.13	Tr.	0.016	0.013	0.10	3.04	−11.93	−12.65	−11.93	−10.05		
1A7	0.08	0.05	0.020	0.017	0.18	7.20	−16.92	−12.65	−17.32	−10.05		
8A5	0.81	0.12	0.024	0.024	0.22	4.6	−10.20	−14.65	−13.86	−16.30		
8A7	0.66	0.14	0.025	0.050	0.26	7.0	−11.52	−16.05	−15.90	−16.30		
8A10	0.67	0.09	0.034	0.024	0.11	9.1	−15.40	−16.05	−14.90	−16.30		
8A15	0.86	0.40	0.032	0.018	0.23	14.9	− 8.77	−13.15	−13.03	−14.05		
	C steels; *see also* Tables 3, 5; An. from 900°C, cooling 8.5 hr; Qu. at 950°C in water at 15°C*											
H1	0.07	0.03	0.005	0.013	0.00		+11.93	+ 8.55	+12.59	+ 8.73		
H2	0.24	0.03	Tr.	0.015	0.03		+11.11	+ 7.65	+ 9.99	+ 6.93		
H3	0.44	0.08	Tr.	0.016	0.05		+ 9.68	+ 6.20	+ 5.20	+ 3.46		
H4	0.79	0.09	0.006	0.009	0.00		+ 8.05	+ 5.40	+ 0.92	− 1.32		
H5	1.12	0.06	Tr.	0.022	0.02		+ 6.02	+ 4.10	− 5.25	− 5.70		
H6	1.58	0.09	Tr.	0.016	0.04		+ 6.73	+ 4.15	− 6.52	− 5.80		

For H1 to H5, coefficients of Q_{Cu} are: 0° t 700°, a = A, b = −0.563A, c = +0.5A, where A ≡ 18.8 − 10.5C + 4.1C^2, carbon content = C%; t_2 t t_3, a = −5.9 − 0.01bt_2, b = −0.38; t_3 t 1000°, a = −10.5 − 0.01bt_3, b = −2.8; t_2, t_3 = temperatures of transformations A_2, A_3 (18). For pure Fe, t_2 = 730°, t_3 = 950°; increasing C decreases both; with more than 0.4% C they coincide at *ca.* 700° (18). For piano wire, coefficients of E_{Pb} −200° t 100° are: a = +10.763, b = −1.5586, c = −18.762 (31).

						Cr						
	Cr steels; *see also* Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*											
1C1	0.06	Tr.	0.016	Tr.	0.70	1.20	+17.87	+16.93	+ 6.83	+16.4	+17.43	+16.6
1C2	0.08	0.08	0.015	Tr.	0.12	1.89	+15.72	+16.65	+14.78	+15.20	+15.51	+16.6
1C3	0.28	0.15	0.010	Tr.	0.05	2.66	+17.28	+18.11	+14.88	+21.50	+14.99	+17.10
1C7	0.07	Tr.	0.010	0.014	0.12	7.84	+ 9.94	+14.92	+ 9.99	+13.50	+ 8.67	+12.70
1C10	0.42	Tr.	0.010	Tr.	0.35	9.80	+12.40	+14.74			+ 6.97	+ 5.82
1C12	0.14	Tr.	0.016	0.015	0.21	13.60	+ 6.63	+10.56	+ 5.20	+ 7.65	+ 6.27	+ 8.73
1C25	0.24	0.10	0.022	0.013	0.26	25.31	+ 6.38	+ 9.01	+ 6.40	+ 5.09	+ 4.25	+ 6.28
1C30	0.46	Tr.	0.024	0.006	0.37	31.75	+ 4.37	+ 6.55	+ 5.09	+ 7.86	+ 6.03	+ 9.55
8C1	0.97	0.24	0.013	0.016	0.22	0.92	+ 9.93	+ 8.92	+ 3.97	+ 3.64	+ 9.70	+ 8.83

TABLE 4.—(*Continued*)

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Cr	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
	Cr steels; *see also* Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*											
8C2	0.89	0.10	0.020	0.033	0.28	2.14	+10.41	+ 9.64	+ 3.59	+ 4.20	+ 9.70	+ 9.00
8C5	0.79	Tr.	0.016	0.023	0.42	4.57	+12.40	+12.56	+ 7.13	+ 5.91	+12.53	+12.90
8C7	0.84	0.05	0.018	0.031	0.41	7.27	+11.82	+13.45			+10.40	+11.90
8C10	0.52	0.13	0.024	0.005	0.62	9.85	+11.70	+14.48	+ 5.08	+ 3.58	+ 2.83	+ 3.63
8C12	0.96	0.05	0.013	0.047	0.41	11.52	+10.60	+13.60	+ 7.03	+ 9.70	+ 9.60	+11.90
8C20	0.90	0.05	0.010	0.007	0.74	18.65	+ 5.09	+ 7.95	+ 3.31	+ 4.64	+ 0.83	− 1.55
8C25	0.82	0.05	0.016	0.008	0.58	26.54	+ 3.36	+ 5.91	+ 2.04	+ 4.64	+ 2.90	+ 5.37
8C30	0.92	0.05	0.021	0.012	0.47	32.46	+ 6.97	+ 6.30	+ 4.40	+ 5.55	+ 4.95	+ 6.28
	Mn steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*											
8M0.5	0.87	0.40	0.020	0.024	1.35		− 0.30	− 3.10		− 2.00		
8M1	0.84	1.03	0.024	0.015	0.57		− 0.71	− 2.80	− 5.50	− 6.65		
8M3	0.93	3.08	0.015	0.010	1.44		− 2.65	− 4.70				
8M12	0.96	12.09	0.011	0.013	0.87		− 9.78	−11.80	−10.20	− 6.65		
	1.2	5.0	Ni = 25.0	Hadfield's Mn steel; for E_{Fe}, 0° t 310°, a = +21.8, b = −5.8; for 310° < t < 1100°, E_{Fe} = +3975 ± 50 (5)								
	(?)	12	(?)	Hadfield's Mn steel; for E_{Pb}, −200° t +100°; before annealing, a = − 5.591, b = −0.5152, c = +0.390; after An. from 600°, a = −5.067, b = −0.3582, c = +2.337 (31)								
						Mo						
	Mo steels; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*											
1Mo0.5	0.19	0.07	0.018	0.009	0.12	0.45	+10.20	+ 8.35				
1Mo1	0.16	0.10	0.018	0.032	0.11	1.00	+11.01	+ 7.70	+10.20	+ 8.00		
1Mo2	0.14	0.17	0.021	0.009	0.12	2.20	+10.90	+ 7.80	+10.30	+ 7.92		
1Mo5	0.29	0.50	0.026	0.039	0.12	4.50	+ 8.77	+ 6.30	−12.23	+ 3.98		
8Mo0.5	0.78	0.26	0.021	0.032	0.21	0.50	+ 4.59	+ 3.00	− 4.48	− 6.50		
8Mo1	0.81	0.40	0.040	0.018	0.02	1.21	+ 4.79	+ 3.20				
8Mo2	0.81	0.30	0.016	0.034	0.017	1.98	+ 5.30	+ 4.30	+ 1.12	+ 0.10		
						Ni						
	Ni steels;† *see also* Table 3; An. from 900°C, cooling 7 hr; Qu. at 950°C in water at 18°C*											
1N2	0.07	0.02		0.006	0.07	2.23	+ 9.07	+ 6.3	+10.91	+ 6.2	+ 8.97	+ 6.5
1N5	0.12	0.01		0.004	0.05	5.23	− 0.61	− 3.5	+ 0.2	− 3.4	− 0.61	− 3.2
1N7	0.12	0.12		0.005	0.05	7.13	− 4.89	− 7.8	− 4.99	− 7.6	− 4.89	− 7.6
1N10	0.13	Tr.		0.005	0.10	10.10	−10.8	−14.6	−11.11	− 9.7	−11.21	−13.5
1N12	0.12	Tr.		0.002	0.09	12.07	−14.58	−16.9	−14.78	−17.0	−18.45	−17.4
1N15	0.11	Tr.		0.004	0.02	15.17	−19.38	−23.5	−18.75	−23.9	−20.28	−24.3
1N20	0.18	Tr.		0.004	0.02	20.40	−28.96	−30.4	−33.22	−31.3	−27.83	−30.0
1N25	0.16	Tr.		0.007	0.04	25.85	−32.0	−11.5	−33.22	−31.3	−31.08	−27.8
1N30	0.12	Tr.		Tr.	0.03	30.00	−15.08	− 6.9	−14.98	− 1.0	−15.49	− 1.5
4N2	0.21	0.02		Tr.	0.03	1.97	+ 8.66	+ 7.0	+ 8.05	+ 5.5	+ 8.25	+ 6.3
4N5	0.20	0.02		0.03	0.04	4.90	+ 1.73	− 2.4	+ 0.71	+ 2.0	+ 0.0	− 2.3
4N7	0.23	0.05		Tr.	0.08	7.59	+ 4.18	− 7.3	− 3.26	− 6.0	− 4.38	− 6.8
4N10	0.21	0.02		Tr.	0.01	9.79	+ 9.88	−12.6	− 9.88	−11.6	− 9.58	−12.9
4N12	0.22	0.02		0.002	0.01	12.29	+13.25	−15.3	−11.92	−15.7	−13.67	−16.4
4N15	0.22	Tr.		0.002	0.05	15.04	+16.61	−27.3	−16.31	−19.1	−17.63	−10.6
4N20	0.22	0.02		0.003	Tr.	20.01	+22.87	−30.6	−22.43	−23.7	−22.43	−21.5
4N25	0.23	0.02		0.003	0.08	25.06	+17.73	− 7.1	−19.98	−12.7	−14.88	− 3.8
4N30	0.19	0.02		0.002	0.03	27.87	+ 8.05	− 2.3	− 9.37	− 0.9	− 4.18	− 1.9
9N2	0.80	0.10		0.005	0.10	2.30	+ 6.52	+ 4.7	+ 5.91	+ 4.6	+ 5.81	+ 4.6
9N5	0.78	0.09		0.004	0.08	4.90	+12.53	− 3.0	− 1.02	− 2.6	− 1.02	− 2.6
9N7	0.81	0.12		0.003	0.10	7.09	− 5.10	− 6.9	− 4.18	− 5.9	− 3.97	− 5.9
9N10	1.05	0.10		0.004	Tr.	9.79	− 7.34	− 8.5	− 7.24	− 8.5	− 8.15	− 8.7
9N12	0.76	0.09		0.004	0.09	12.27	− 7.95	− 9.4	− 8.87	− 9.8	−10.30	−10.4
9N15	0.80	0.06		0.007	0.09	15.04	−12.13	−11.1	−10.30	−10.1	− 9.38	− 4.9
9N20	0.80	0.02		0.003	0.09	20.01	−12.53	− 6.6	− 5.10	− 5.0	− 6.93	− 3.5
9N25	0.79	0.07		0.002	Tr.	25.06	−12.43	− 6.1	− 4.69	− 4.9	− 2.95	− 2.6
9N30	0.81	0.03		0.004	0.14	29.96	− 5.71	− 1.8	− 3.36	− 2.0	− 2.95	− 1.9

TABLE 4.—(*Continued*)

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Ni	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
Si steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*												
1S0.5	0.21	0.72	0.117	0.061	0.41		+ 2.14	− 0.30	+ 1.12	− 0.90		
1S1	0.21	Tr.	0.024	0.020	0.93		− 2.95	− 6.10	− 1.32	− 5.00		
1S2	0.18	0.27	0.032	0.012	1.60		− 4.89	− 8.28	− 5.10	− 8.40		
1S3	0.28	0.38	0.034	0.009	5.12		− 6.93	−10.80	− 7.03	−10.40		
8S1	0.84	0.57	0.021	0.017	1.16		− 3.46	− 6.00				
8S2	0.83	0.41	0.021	0.017	1.15		− 6.93	− 9.90	− 7.85	−10.20		
8S3	0.94	1.44	0.062	0.017	5.54		− 8.36	−12.00	− 9.07	−10.70		
						W						
W steels; An. from 900°C, cooling 8.5 hr; Qu. at 1000°C in water at 14°C*												
1T0.5	0.18	Tr.	0.013	Tr.	0.03	0.41	+ 9.18	+ 6.30	+ 8.56	+ 5.70		
1T1	0.11	Tr.	0.016	0.005	0.06	0.93	+ 8.56	+ 5.98	+ 7.85	+ 5.65		
1T2	0.11	Tr.	0.010	0.008	0.03	1.75	+ 7.75	+ 5.24	+ 6.83	+ 4.75		
1T5	0.13	Tr.	0.015	Tr.	0.03	4.96	+ 7.95	+ 6.25	+ 7.34	+ 5.20		
1T15	0.20	Tr.	0.013	0.008	0.06	14.37	+ 7.75	+ 6.40	+ 7.95	+ 7.40		
1T20	0.22	Tr.	0.011	0.013	0.14	20.71	+ 8.00	+ 6.30	+ 8.05	+ 7.25		
8T0.5	0.86	0.027	0.012	0.033	0.04	0.40	+ 1.84	− 0.08	− 1.63	− 4.15		
8T2	0.66	0.054	0.015	0.023	0.12	1.95	+ 2.55	+ 0.50	+ 1.12	− 1.70		
8T10	0.81	Tr.	0.015	0.014	0.09	9.99	+ 5.00	+ 3.00	+ 2.85	+ 1.30		
8T15	0.71	Tr.	0.015	0.023	0.12	14.74	+ 2.75	+ 0.60	+ 2.85	− 1.40		

* An. = annealed, time in furnace = 3 hr, time of cooling is as indicated. Qu. = quenched, specimen in furnace 11 or 12 min and for 2 min was at temperature indicated.

† For 1N and 4N groups, changes in heat treatment produce slight effect; maximum negative value of E occurs at *ca.* 25 % Ni in 1N and *ca.* 20 % Ni in 4N group.

TABLE 5.—THERMOELECTROMOTIVE FORCE (E) OF CARBON STEELS: EFFECT OF HEAT TREATMENT [23]; *see also* Table 4

Specimens were quenched at 903 or 908°C, kept at 97 to 102°C for 48 hr, then heated (drawn) to temperature indicated and kept at that temperature for 1 to 2 hr, then allowed to cool slowly in furnace. Error in E not greater than 10μv. For all 8 specimens, the smallest negative value of E corresponds to drawing temperature of 696°C. Unit of E = 1μv = 10^{-6} volt; of admixture = 1%; temperature, °C.

Symbol	Admixture					Quenched		Drawn							
						903°	908°	100°	205°	309°	388°	495°	599°	696°	800°
	C	Mn	P	S	Si	E_{IN2} (junctions at 0° and 100°C)									
C04	0.04	0.10	0.007	0.029			− 74	− 36	− 34	− 29	− 34	− 29	− 29	− 26	− 29
M16	0.30	0.204	0.012	0.013	0.033		−310	−278	−230	−170	−136	−102	− 94	− 83	−100
H35	0.35	0.08	0.009	0.024	0.18		−575	−537	−499	−452	−437	−419	−414	−400	−413
H41	0.41	0.08	0.012	0.016	0.19		−615	−578	−529	−474	−444	−434	−429	−414	−420
H57	0.57	0.11	0.010	0.020	0.17		−707	−627	−537	−474	−444	−419	−414	−394	−417
C4	0.76	0.221	0.016	0.041	0.169	− 950		−718	−577	−474	−439	−410	−404	−350	−393
C5	0.945	0.189	0.013	0.061	0.155	−1170		−795	−608	−458	−410	−392	−376	−364	−378
C7	1.05	0.190	0.013	0.020	0.167	−1308		−916	−713	−556	−516	−509	−497	−467	−473
IN2	0.018	0.011	0.006	0.018	Cu = 0.018 = pure ingot iron = reference metal										

TABLE 6.—THERMOELECTRIC POWER (Q) OF OXIDES AND SULFIDES

R = reference metal, Q_R = a + bt if t lies between t_1 and t_2. Unit of Q = 1μv/°C = 10^{-6} volt/°C; t_1, t_2 = centigrade temperature, °C.

Oxide	R	t_1	t_2	a	b	Lit.
Bi_2O_3	Pb†	500	800	+ 1 946	− 1.86	(11)
CdO	Pb†	100	1 065	− 32	− 0.030	(11)
Co_3O_4	Pb†	200	1 200	+ 629	− 0.221	(11)
Cr_2O_3	Pb†	950	1 285	− 704	+ 0.432	(11)
CuO	Pb†	170	850	− 1 029	+ 1.715	(11)
	Cu*	0	700	+ 1 190	− 0.38	(20)
Cu_2O	Cu*	0	700	+ 1 052.5	− 0.75	(20)
FeO	Cu	50	50	Q_{Cu} = + 500		(52)
Fe_2O_3	Cu	50	50	Q_{Cu} = + 60		(52)
Fe_3O_4	Pb†	170	875	− 54.6	− 0.026	(11)
	Pb†	875	1 485	− 53.2	− 0.018	(11)
	Fe*	0	700	− 427	0.00	(20)
FeS	Cu	50	50	Q_{Cu} = − 26		(52)
FeS_2	Cu	50	50	Q_{Cu} = + 200		(52)
Mn_2O_3	Pb†	200	1 200	+ 628	− 0.332	(11)
MnO_3H_2	Cu	50	50	Q_{Cu} = + 200		(52)
MoS	Cu	50	50	Q_{Cu} = + 770		(52)
NiO	Pb†	400	1 200	+ 254	− 0.065	(11)
PbO	Pb†	250	390	−48 300	+117.2	(11)
	Pb†	390	550	− 6 000	+ 9.22	(11)
	Pb†	550	850	− 3 914	+ 5.43	(11)
SnO	Pb†	0	1 200	− 90	− 0.437	(11)
U_3O_8	Pb†	65	1 265	+ 96	− 0.157	(11)
WO_3	Pb†	140	970	− 18.4	− 0.053	(11)
ZnO	Pb†	355	1 350	− 735	+ 0.259	(11)

* Error in E = ±200 microvolt. † Used Pt as reference metal, but expressed results in terms of Q_{Pb}.

TABLE 7.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF METALS

${}_sE_o$ = thermo emf around a circuit composed of two specimens of the same material, one specimen (s) is stressed, the other (o) not stressed; one junction is at 0°C and the other is at t, °C; ${}_sE_o$ is positive if the current flows from the stressed to the unstressed specimen at the junction at 0°C.

If p = hydrostatic pressure upon the stressed specimen; τ = longitudinal tension upon the stressed specimen; t = temperature (°C); f, g, h, m, n are constants depending upon the metal; then if $\tau = 0$, ${}_sE_o = fpt\{1 + gp(10^{-6})\}\{1 + ht(10^{-3})\}$; ${}_sQ_o = kp$, where $k = f\{1 + gp(10^{-6})\}\{1 + 0.5ht(10^{-3})\}$; $k = f$ if $g = 0$, $h = 0$. If $p = 0$, ${}_sE_o = 1000m\tau + n\tau^2$.

The numbers in the "Error" column indicate the probable uncertainty in the value of ${}_sE_o$. Unit of $E = 1\mu\mu v = 10^{-12}$ volt; of p and $\tau = 1$ kg/cm² = 14.22 lb./in.² = 0.968 A_n; of "Error" = 10^{-6} volt; t = centigrade temperature, °C.

Symbol	Tension (17)*			Pressure (17)†				${}_sQ_o$ (78)‡
	t	m	n	f	g	h	Error	k
Ag				+ 8.34	− 6.8	+1.47	±0.02	+ 8.7
Al	50.5	+ 8.8	− 6.7	*See* Table 8				− 0.59
	76	+ 8.8	− 4.7					
Au				+ 4.40	− 8.2	+2.0	±0.01	+ 4.61
Bi				+513	+37.4	−0.06	±4	+707§
Brass	52	− 0.22	+ 0.03					
	77	− 0.13	+ 0.012					
	94	− 0.47	+ 0.05					
Cd				+ 21.3	+ 6.0	+6.3	±0.5	+ 36.3
Co				− 14.4	− 1.43	+2.07	±5%	
Constantan‖				+ 27.9	0	+0.62	±0.1	+ 28.7
Cu	95	+ 0.56		+ 2.58	− 2.2	+1.9	±0.15	+ 3.15
Fe	52	+12.0¶	−23.5	*See* Table 8				+ 12.5
	95	+22.3¶	−42					
Hg**						t =		
						20 − 80		+194
						106 −151		+294
						114 −167		+340
						228 −270		+478
						250 −300		+466
						304 −346		+449
						0 −100		+234
Manganin		Variable††		− 1.31	0	−1.57	±0.04	− 8.5
Mg				− 8.2	+26.0	0	±0.02	− 8.9
Mo				+ 0.099‡‡	0	+278.0−2.18t		
Ni	31	+ 3.35	− 0.60	+ 6.11	+16.5	+3.06	±0.015	+ 9.6
	51	+ 5.77	− 1.32					
	77.5	+ 8.1	− 1.75					
	94.5	+12.1	− 3.7					
Pb				+ 4.09	0	+2.9	±0.01	+ 5.6
Pd				+ 20.8	+ 1.07	+0.5	±0.1	+ 23.7
Pt				+ 13.94§§	0	+9.64 − 0.0676t		+ 18.6
				+ 14.3‖‖	+15.6	+0.87	±0.17	
Sn				*See* Table 8				− 0.95§
Tl				+ 44.4	−17.0	+2.4	±0.2	
W				+ 10.86	0	+1.61	±0.1	
Zn				+ 59.3	0	+2.23	±0.2	
							t = 43	+ 39
							t = 58	+ 57

* For τ between 0 and τ_m; values of τ_m and of error in ${}_sE_o$ as follows:

Metal	Al	Fe	Cu	Ni	Brass	Manganin
τ_m	(?)	500	700	2000	2800	1300
Error	±5 %	±5 %	±10 %	±2.5 %	±8 %	

† Range in p 2 000 to 12 000 kg/cm²; in t is 0 to 100°C.

‡ Range in t is 0 to 100°C, in p is 1 to 300 kg/cm² (78), probable error in ${}_sQ_o$ *ca.* 1.5 %; for (74) $t \leq 400$°C, $p \leq 55$ kg/cm²; probable error in ${}_sQ_o$ *ca.* ±3 %.

§ For liquid metal, $k < +4$ (74).

‖ Constantan = 54 % Cu, 43.6 % Ni, 1 % Mn, 1.4 % Fe.

¶ Annealed ingot iron.

** For 20 to 80° (3, 30, 74); for 0 to 100° (78); for others (74).

†† For some samples ${}_sE_o > 0$, for other ${}_sE_o < 0$; maximum value observed was ${}_sE_o = 1.33 \times 10^{-6}$ volt.

‡‡ Error in ${}_sE_o = \pm 0.1 \times 10^{-6}$ volt.

§§ Heraeus' pure Pt; error in ${}_sE_o = \pm 0.1 \times 10^{-6}$ volt. Source of specimen for ${}_sQ_o$ is not stated.

‖‖ Baker's commercial.

TABLE 8.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF AL, FE, AND SN (17)

For explanation of symbols, *see* Table 7. Unit of ${}_sE_o = 1\mu v = 10^{-6}$ volt; of $p = 1$ kg/cm² = 14.22 lb./in.² = 0.968A_n; t = centigrade temperature, °C.

p	2 000	4 000	6 000	8 000	10 000	12 000
t	$1000\,{}_sE_o/t$, "Pure" Al					
10	−3.1	−4.8	−6.8	−7.0	− 7.6	− 6.9
20	−2.7	−4.05	−4.9	−4.9	− 4.75	− 3.4
30	−2.27	−3.33	−3.8	−2.97	− 1.87	+ 0.1
40	−1.82	−2.60	−2.58	−1.15	+ 0.75	+ 3.25
50	−1.40	−1.82	−1.26	+0.64	+ 3.16	+ 6.24
60	−0.97	−1.00	+0.08	+2.43	+ 5.47	+ 9.05
70	−0.50	−0.11	+1.47	+4.23	+ 7.69	+11.7
80	−0.025	+0.82	+2.89	+5.98	+ 9.82	+14.39
90	+0.48	+1.84	+4.32	+7.66	+11.89	+17.01
100	+1.01	+2.94	+5.77	+9.29	+13.84	+19.62

If $p < 6500$, ${}_sE_o(10)^6 = [-2.167p + 0.131(10)^{-3}p^2]t + [24.5\ (10)^{-3}p - 0.2(10)^{-6}p^2]t^2$. If $p > 6500$, ${}_sE_o(10)^6 = [-11.09(10)^3 + 0.497p - 14(10)^{-6}p^2] + [144.6 - 9.85(10)^{-3}p + 1.675(10)^{-6}p^2]t^2$. Mean probable error in ${}_sE_o$ is $\pm 10^{-8}$ volt = 0.01μv.

t	$1000\,{}_sE_o/t$, Commercial Al					
10	−1.2	−1.9	−1.7	− 2.0	− 0.6	+ 1.8
20	−0.95	−1.4	−0.95	0.0	+ 2.5	+ 5.8
30	−0.77	−0.90	−0.07	+ 1.9	+ 5.13	+ 8.83
40	−0.48	−0.25	+1.00	+ 3.70	+ 7.32	+11.60
50	−0.16	+0.52	+2.34	+ 5.40	+ 9.60	+14.40
60	+0.18	+1.40	+3.78	+ 7.33	+12.12	+17.50
70	+0.57	+2.31	+5.33	+ 9.57	+14.79	+21.04
80	+1.00	+3.25	+6.87	+11.80	+17.25	+24.70

Mean probable error in ${}_sE_o = \pm 10^{-8}$ volt = 0.01μv.

t	$1000\,{}_sE_o/t$, Fe, Ingot, An.*					
20	− 4	− 7.5	−14	−25	−37	−49.5
40	+ 4.2	+ 5.5	+ 5.5	+ 0.5	− 3.2	−10.2
60	+11.0	+18.0	+21.2	+21.8	+24.2	+23.3
80	+15.1	+28.5	+39.4	+48.9	+56.0	+61.1
100	+16.7	+32.5	+46.0	+58.2	+68.6	+76.8

t	$1000\,{}_sE_o/t$, Fe, Ingot, Hd.*					
20	+ 1	− 7.5	−12	−22.5	− 27	− 37
40	+ 5.8	+ 4.5	+ 5.2	− 0.5	+ 2.5	+ 0.2
60	+10.3	+17.3	+23.8	+25.7	+ 30.8	+ 36.7
80	+15.9	+30.2	+42.5	+52.5	+ 63.9	+ 76.5
100	+23.0	+44.2	+66.9	+87.0	+107.0	+128.0

t	$1000\,{}_sE_o/t$, Fe, Soft*					
20	− 1.5	− 5.5	−14.5	−25	−37.5	−56
40	+ 3.8	+ 5.5	+ 1.8	− 3.8	−10.0	−20.5
60	+ 7.7	+13.7	+15.5	+14.7	+12.5	+ 7.3
80	+12.7	+23.1	+30.9	+36.8	+39.8	+39.9
100	+23.4	+42.0	+56.8	+69.4	+82.5	+95.6

* An. = Pure American ingot iron, annealed; Hd. = same as An., but hard-drawn; soft = commercial soft iron wire. Mean probable error in ${}_sE_o$ is $\pm 5 \times 10^{-7}$ volt = 0.5μv.

t	$1000\,{}_sE_o/t$, Sn					
10	+0.1	−0.4	−1.4	−4.1	−8.3	−13.6
20	+0.15	0.0	−0.5	−2.25	−5.15	− 9.1
30	+0.40	+0.40	+0.37	−0.67	−2.50	− 5.13
40	+0.60	+0.82	+1.05	+0.52	−0.48	− 2.02
50	+0.76	+1.16	+1.56	+1.40	+0.96	+ 0.20
60	+0.87	+1.38	+1.85	+2.03	+1.95	+ 1.72

TABLE 8.—(*Continued*)

p	2 000	4 000	6 000	8 000	10 000	12 000
t	$1000\,{}_sE_o/t$, Sn					
70	+0.91	+1.52	+2.09	+2.46	+2.61	+ 2.73
80	+0.92	+1.59	+2.20	+2.72	+3.04	+ 3.36
90	+0.91	+1.63	+2.29	+2.87	+3.29	+ 3.72
100	+0.87	+1.65	+2.32	+2.92	+3.41	+ 3.90

Mean probable error in ${}_sE_o$ is $\pm 2 \times 10^{-8}$ volt = 0.02μv.

TABLE 9.—EFFECT OF LONGITUDINAL MAGNETIC FIELD (H) AND OF TENSION (τ) UPON THERMOELECTRIC PROPERTIES OF METALS (12)

${}_{\tau H}E_o$ = thermo emf around a circuit composed of two specimens of the same material, one specimen (τH) is subjected to tension τ and field H; for the other specimen (o), $\tau = 0$, $H = 0$; one junction is at t_1, °C and the other at t_2, °C. ${}_{\tau H}Q'_o = {}_{\tau H}E_o/(t_2 - t_1)$. In certain cases, ${}_{\tau H}Q_o = a(1 - e^{-0.001bH})$ if τ, t_1 and t_2 are kept constant. H_m is value of H at which ${}_{\tau H}Q_o$ is a maximum.

In general, the algebraic value of ${}_HQ_o$ decreases as the hardness, the intensity of magnetization, and $(t_2 - t_1)$ increase, either individually or collectively.

For the following data, $t_1 = 14$°C, $t_2 = 100$°C; probable error in $Q' = ca.\ 0.5 \times 10^{-6}$ volt/°C. Unit of Q' and $a = 1$mμv/°C = 10^{-9} volt/°C; of $H = 1$ gauss; of $\tau = 1$ kg/cm² = 14.22 lb./in.²; of $b = 1$ gauss^{-1}.

Metal	H	400	450	800	∞	Maximum		a	b
	τ	${}_{\tau H}Q'_o$				${}_{\tau H}Q'_o$	H_m		
Co*.....	0	+ 90	+ 91	+ 96	+ 97			+ 97	−6.4
Co†.....	0	+ 60	+ 64	+ 81	+ 93			+ 93	−2.6
Fe‡.....	0	+ 80		+ 53	+ 44	+110	100		
	1620		0	− 28	− 40	+ 35	40		
Fe, C§....	0	+ 50			+ 35	+ 68	200		
Ni‖.....	0	+329	+336	+353	+355			+355	−6.5
	447	+382	+386	+390	+392			+392	−9.2
	970	+408	+424	+480	+485			+485	−4.6

* Cast. † Rolled. ‡ Pure Fe, Q' rises rapidly to a maximum, and then decreases. If $H > 200$, ${}_HQ_o$ for annealed Fe is 40×10^{-9} volt/°C less than ${}_HQ_o$ for unannealed iron. For soft Fe, ${}_HQ_o > 0$; for annealed steel, ${}_HQ_o < 0$. § Hard steel. ‖ Annealed.

TABLE 10.—EFFECT OF MAGNETIC FIELD (H) AND TENSION (τ) UPON THERMO EMF OF BIMETALLIC CIRCUITS (75)

$\Delta E/E = ({}_ME'_{Cu} - {}_ME_{Cu})/{}_ME_{Cu}$, where ${}_ME'_{Cu}$ = thermo emf of the M − Cu circuit when M is subjected to H and τ, ${}_ME_{Cu}$ = thermo emf of the same circuit when $H = 0$, $\tau = 0$; the temperatures (t_1, t_2) of the junctions are the same for ${}_ME'_{Cu}$ as for ${}_ME_{Cu}$. Probable error in $\Delta E/E = ca.\ 2\%$ of $\Delta E/E$. The composition of each metal M is stated in the table. H_m = value of H at which $\Delta E/E$ is a maximum. Unit of $H = 1$ gauss; of $\tau = 1$ kg/cm² = 14.22 lb./in.²; of composition of $M = 1$ wt. %.

A. Longitudinal magnetic field; $t_1 = 0$°C, $t_2 = 100$°C

M		H	200	400	800	∞	Maximum, $\Delta E/E$	H_m
Fe	Cu	τ	$1000\Delta E/E$					
100	0	0	+14.1	+10.8	+ 7.6	+ 6.0	+15.3	100
		516	+ 8.7	+ 5.25	+ 2.1	+ 0.5	+10.3	90
		1050	+ 2.85	− 0.75	− 3.9	− 6.0	+ 4.7	90
		2090	− 4.65	− 7.95	−11.4	−13.6	−13.6	∞
99.2	0.8	0	+18.6	+15.75	+12.9	+10.5	+19.2	150
		741	+13.35	+10.35	+ 7.3	+ 5.0	+14.7	110
		935	+ 8.85	+ 5.85	+ 2.48	+ 0.5	+10.5	100
		1860	+ 3.0	0.0	− 3.75	− 6.5	+ 4.6	60
98.5	1.5	0	+52.5	+43.5	+34.0	+27.0	+56.0	100
		1020	+31.5	+21.0	+10.5	+ 2.0	+36.0	100
		2040	+11.0	+ 0.5	−11.0	−20.0	+17.0	75

TABLE 10A.—(*Continued*)

M		*H*	200	400	800	∞	Maximum, $\Delta E/E$	H_m
Fe	Cu	τ	$1000\Delta E/E$					
98.0	2.0	0	+38.5	+32.5	+25.0	+21.0	+40.0	120
		1190	+25.5	+18.5	+11.0	+ 4.0	+28.5	100
		2370	+11.3	+ 4.0	− 5.8	−10.5	+15.3	75
96	4	0	+28.8	+25.0	+20.5	+17.0	+29.5	120
		1100	+21.5	+17.0	+11.8	+ 7.5	+22.5	110
		2200	+13.3	+ 8.5	+ 3.0	− 1.0	+14.9	100
94	6	0	+26.0	+21.0	+15.6	+12.0	+29.0	100
		930	+14.0	+ 8.0	+ 2.5	− 1.5	+18.0	80
		1850	+ 5.5	− 0.5	− 7.5	−13.5	+10.0	70
93	7	0	+44.5	+34.5	+25.5	+18.5	+49.3	95
		1160	+24.0	+13.0	+ 2.8	− 6.0	+31.0	90
		2310	+ 3.0	− 8.5	−20.0	−29.0	+12.0	70
Fe	Ni							
98.9	1.1	0	+24.8	+19.3	+15.8	+12.1	+27.0	100
		964	+14.0	+ 8.5	+ 3.4	+ 0.5	+16.6	95
		1920	+ 4.5	− 0.9	− 6.5	−10.0	+ 7.0	80
98.1	1.9	0	+45.0	+37.5	+29.8	+25.0	+48.0	100
		984	+26.0	+17.7	+10.0	+ 5.0	+32.0	90
		1960	+ 9.5	+ 1.5	− 7.0	−12.5	+14.0	70
93	7	0	+ 5.3	+ 5.05	+ 4.6	+ 4.1	+ 5.4	240
		963	+ 3.6	+ 3.2	+ 2.7	+ 2.1	+ 2.7	120
		1920	+ 1.95	+ 1.4	+ 0.95	+ 0.45	+ 2.25	100
88.7	11.3	0	+ 2.6	+ 3.2	+ 3.2	+ 2.9	+ 3.25	500
		931	+ 2.5	+ 2.8	+ 2.85	+ 2.5	+ 2.87	700
		1860	+ 2.1	+ 2.5	+ 2.45	+ 2.1	+ 2.5	430
0	100	0	+ 7.00	+ 8.70	+ 9.60	+ 9.75	+ 9.75	∞
		1290	+ 6.25	+10.50	+12.90	+13.30	+13.30	∞
		2610	+ 3.85	+ 9.00	+13.80	+14.75	+14.75	∞

B. Transverse magnetic field; $t_1 = 22°C$, $t_2 = 100°C$

M	$\tau = 0$		$\tau = 1370$		$\tau = 2070$	
Ni	*H*	$1000\Delta E/E$*	*H*	$1000\Delta E/E$*	*H*	$1000\Delta E/E$*
100%	3000	+ 9.0	3100	+5.9	3100	+4.8
	5900	+12.5	5750	+8.6	5750	+5.7
	8500	+16.5	8400	+8.4	8400	+5.6

* Change due to H, τ being constant.

TABLE 11.—PELTIER COEFFICIENT: DIRECTLY OBSERVED

For all couples including constantan, *see* Table 12

When $_MP_R$ is positive, there is an absorption of heat as the current passes from *R* to *M*. When *M* is a binary alloy, the % by weight of the second component appears under the symbol of that component. The coefficients for other couples can be computed from data in Tables 1 to 6; the accuracy of values so computed probably exceeds that of those directly measured. Unit of P = $1\mu v = 10^{-6}$ volt; of "Error" = 1% of P; t = centigrade temperature, °C.

M		*R*	*t*	$_MP_R$	Error	Lit.
Ag		Cu	0	+ 480	2	(50)
		Cu	0	− 68	2	(14)
		Cu	18	− 30	30	(24)
Ag	Pd				2	(14)
	0	Cu	0	− 68		
	10		0	− 1 593		
	20		0	− 2 215		
	30		0	− 3 240		
	40		0	− 4 960		
	50		0	− 8 650		
	60		0	− 9 980		
	70		0	− 8 500		
	80		0	− 6 150		
	90		0	− 4 290		
	100		0	− 2 380		

TABLE 11.—(*Continued*)

M		*R*	*t*	$_MP_R$	Error	Lit.
Ag	Sn					
	70	Cu	20	− 674	2	(14)
Al		Cu	15.8	− 695	1.5	(24)
Au		Cu	0	− 329	2	(14)
Au	Pd				2	(14)
	0	Cu	0	− 329		
	10		0	− 2 086		
	20		0	− 2 865		
	30		0	− 7 710		
	40		0	− 10 610		
	50		0	− 8 200		
	60		0	− 6 720		
	70		0	− 6 210		
	80		0	− 5 870		
	90		0	− 4 810		
	100		0	− 2 380		
Bi ⊥*		Cu	8.1	− 14 620	2–3	(51)
			20.6	− 15 730	2–3	(51)
			22.4	− 15 700	2–3	(51)
			19.75	− 14 120	2	(16)
Bi‖		Cu	20.5	− 21 060	2	(16)
Bi(45)*		Cu	19.5	− 23 300	2	(16)
Bi†		Cu	18	− 16 130	1	(24)
		Cu	20.7	− 19 350	2	(24)
		Cu	25	− 22 300	4	(57)
Bi	Sn					
	3.75	Cu	20.7	+ 10 870	2	(24)
	6.36		20.7	+ 11 670	2	(24)
	9.93		20.7	+ 10 450	2	(24)
C		Cu	20(?)	− 2 943	3	(40)
Cd‡		Cu	0	+ 682	2	(7, 25, 50, 57)
Cu	*See* other metal in column *M*					
Cu Ni Constantan	*See* Table 12					
Cu, Ni, Zn§		Cu	20	− 7 400	2	(14)
Fe		Cu	0	+ 3 680	3	(50)
		Cu	19	+ 2 893	3	(40)
		Cu	20	+ 2 995	2	(14)
		Cu	25	+ 2 930	4	(57)
		Hg‡	18.5	+ 4 880	2	(63)
		Ni	15	+ 9 600		(7)
German silver, *see* Cu, Ni, Zn						
MoS_2		Cu	23.5	−173 500	20	(40)
Ni‡		Cu	0	− 5 070	2	(4, 7, 24, 25, 50)
Nickelin¶		Cu	20	− 5 540	2	(14)
Pd		Cu	0	− 2 380	2	(14)
		Cu	0	− 2 920	2	(14)
Pd	Pt				2	(14)
	0	Cu	0	− 2 920**		
	10		0	− 738		
	20		0	+ 51		
	30		0	+ 284		
			20	− 296		
	40		0	+ 170		
			20	− 188		
	50		0	− 79		
	60		0	− 250		
	70		0	− 545		
	80		0	− 748		
	90		0	− 1 134		
	100		0	− 1 531		
Pt		Cu	0	− 1 531	2	(14)
		Cu	0	− 370	3	(50)
		Cu	17.1	− 845	1.3	(24)
		Cu	20	− 1 070	2	(14)
Sb		Cu	25	+ 5 640	4	(57)
Si		Cu	19	+175 100	15	(40)
Zn‡		Cu	0	+ 684	3	(7, 50, 57)

* Bi ⊥, Bi‖, Bi_{45} = current perpendicular, parallel, at 45° to axis of Bi crystal. *See also* Table 13. For *transverse* Peltier effect, *see* p. 214.

† Direction of current with reference to axis of crystal is not stated.

‡ *See* Table 12.

§ German silver, composition is not stated, it usually lies between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn.

¶ Composition is not stated; probably 75 to 55 Cu; 18 to 32 Ni; 0 to 20 Zn.

** Compare with corresponding value for Ag-Pd, Au-Pd by same author.

Table 12.—Peltier Coefficient: Directly Observed Variation with Temperature

Data for other couples may be derived from data in Tables 1 to 6; values so computed are probably more accurate than those directly measured. ${}_MP_R = u + vt + wt^2$ if t lies between t_1 and t_2. Unit of $P = 1\mu v = 10^{-6}$ volt; of "Error" = 1% of P; t_1, t_2 = centigrade temperature, °C.

M	R	t_1	t_2	u	v	w	Error	Lit.
Cd	Cu	0	25	+ 682	− 7.6		2	(7, 25, 50, 57)
Constantan* (Cu, Ni)	Cd	21	570	− 8 710	−41.0	−0.020	2	(25)
	Cu	0	20	−11 340	−61.0		1	(14, 16)
	Cu	15.5	15.5	−10 210				(7)
	Fe	0	560	−12 980	−44.0	−0.051		(7, 25)
	Hg	−80.6	+20	− 8 250	−62.3	−0.32		(25)
	Pb	20	440	− 7 970	−35.1		2	(25)
	Sn	20	570	− 7 710	−34.2	−0.012	2	(25)
Cu (*see* other metal in column M)								
Fe	Hg	18.5	182	+ 4 600	+15.6	−0.034	2	(63)
Ni	Cu	0	445	− 5 070	−23.0	−1.24	2	(4, 7, 24, 25, 50)
Zn	Cu	0	25	+ 684	− 9.2		3	(7, 50, 57)

* Composition is not stated; probably about 60Cu, 40Ni.

Table 13.—Peltier Coefficient of Bismuth: Directly Observed Effect of Magnetic Field (16)

$\Delta P = P' - P$, P' = Peltier coefficient when $H = 2300$ gauss, P = Peltier coefficient when $H = 0$; the direction of the current (∥, ⊥, ∠45°) is referred to the crystallographic c-axis. AB denotes the plane which includes the axis and the direction of the current. Unit of $\Delta P = 1\mu v = 10^{-6}$ volt.

Direction of current	⊥	∥	∠45°
Direction of H	ΔP		
⊥AB	−565	−1393	−2560
∥ AB, ∥ axis	−416	− 226	− 125
∥ AB, ⊥ axis	−264	−1393	−1286
∥ AB, ∥ current	−264	− 226	− 753
∥ AB, ⊥ current	−416	−1393	− 991

Table 14.—Thomson Coefficient (σ): Directly Observed

$\sigma = \alpha + \beta t(10)^{-2} + \gamma t^2(10)^{-5}$ if t lies between t_1 and t_2; when σ is positive, there is an absorption of heat as current flows from regions of higher to those of lower temperature.

For other cases, σ may be computed by means of the relation $\sigma_M - \sigma_R = -T(\partial^2{}_ME_R/\partial t^2)$, using the data in Tables 1 to 6; probably values so computed are more accurate than those directly measured. Unit of $\sigma = 1\mu v/°C = 10^{-6}$ volt/°C; of "Error" = 1% of σ; t_1, t_2 = centigrade temperature, °C.

A. Elementary substances

Symbol	t_1	t_2	α	β	γ	Error	Lit.
Ag	− 168	− 123	− 0.112	+ 9.47	+42	2	(15)
	− 123	+ 127	− 1.17	− 0.50		2	(15)
	+ 123	+ 525	− 3.08	− 0.302		2	(55)
Al	− 13	+ 119	− 0.04	+ 0.475		10	(15)
	+ 71	+ 322	+ 0.2685	+ 0.080		2	(25)
Au	− 173	− 100	− 1.01	+ 0.65	+ 6.1	5	(15)
	− 100	+ 103	− 1.49	− 0.44		5	(15)
Bi*	+ 25	+ 32.5	+ 6.76	+ 2.8		1.5	(54)
	+ 43.5	+ 43.5	+ 58			10	(24)
			+ 5.32			4	(6)
			+ 4.27				(67)
C(1)†			− 4.6				(52)
C(2)†	+1527	+1827	+ 3.7	+ 0.01		5	(81)
Cd	− 163	− 83	− 2.25	− 1.5		5	(15)
	− 83	+ 107	− 5.62	− 5.99	+18.6	5	(15)
	+ 48	+ 343	− 9.00	− 1.55	− 1.5	2	(25)
Cu	− 172	− 60	− 2.244	− 2.5	− 6.4	5	(14, 15)
	− 60	+ 127	− 1.42	− 0.74		5	(15)
	− 96.7	+ 107	− 1.50	− 0.48		2	(9)
	+ 252	+ 678	− 1.37	− 0.235		2	(55)

Table 14A.—(*Continued*)

Symbol	t_1	t_2	α	β	γ	Error	Lit.
Fe‡	− 51	+ 115	+ 4.00	+ 8.4		5	(9)
	+ 32	+ 182	+ 7.66	+ 4.1	+17	3	(43)
	+ 53	+ 308	+ 2.97	+ 1.85		4	(6)
	+ 48	+ 48	+ 11.3			1	(52)
	+ 49	+ 148	− 16.4	+20.8		7	(1)
	+ 91	+ 441	+ 7.785	+ 8.61	−21.4	5	(55)
Hg	+ 50	+ 150	+ 5.065	+ 3.35	+ 1.7	5	(70)
	+ 47	+ 262	+ 1.20	+ 1.58	− 4.8	2	(25, 42)
Pb	− 153	+ 117	+ 0.61	+ 0.221	− 0.38	3	(15)
	+ 45	+ 342	+ 0.03	− 0.47	+ 0.55	2	(25)
Pt	− 72	+ 128	+ 9.10	− 0.475	+ 4.75	1	(9)
Si	+ 46	+ 46	+794			10	(52)
Sn	− 171	+ 112	− 0.09	+ 0.50		5	(15)
	+ 51	+ 266	+ 0.35	+ 0.093		1	(25)
Ta	+1427	+1827	+ 12.5	− 2.0		5	(81)
W	+1227	+1927	− 32.4	+ 3.5		5	(81)
	+1527	+2127	− 12.54	+ 2.0		2	(36)
Zn§	− 173	+ 40	− 2.74	− 1.15		3	(15)
	+ 40	+ 343	− 3.112	− 0.235		2	(25)

B. Alloys and compounds

Alloy	t_1	t_2	α	β	γ	Error	Lit.
Bi-Sn‖							
1.23	+48	+ 76	+ 62.4	+111		1.5	(54)
3.01	+30	+ 72	+ 65.0	+120		1.5	(54)
10.0	+38	+ 75	+ 75.8	+ 39		1.5	(54)
23.6	+25	+ 68	+ 33.3	+ 12		1.5	(54)
1.00	+43.5	+ 43.5	+676			10	(24)
2.00	+43.5	+ 43.5	+537			10	(24)
3.72	+43.5	+ 43.5	+207			10	(24)
6.36	+43.5	+ 43.5	+137			10	(24)
MoS_2¶	+50	+ 50	−113			20	(52)
Constantan**	+87	+481	+ 20.00	+ 2.554	−10.05	10	(55)
	+60	+ 60	+ 19.78			5	(58)
	+20.5	+ 20.5	+ 25.33			5	(14)
German silver**	+23	+ 23	+ 10.45			5	(14)
Manganin**	+60	+ 60	− 2.85			5	(58)
Nickelin**	+31	+ 31	+ 17.14			5	(14)
Piano wire**	+28	+ 28	+ 7.7			5	(14)

* σ varies greatly from one specimen to another. *See also* Table 1.

† C(1) = 70% graphite; C(2) = lamp filament.

‡ Exhibits thermoelectric hysteresis, sometimes as great as 25% of mean σ. The occurrence of signs opposite to those which would be inferred from E is probably due to the presence of impurities.

§ Numerical value of σ increases rapidly between 40 and 100°C.

‖ σ varies from one specimen to another; the % of Sn by weight is indicated below the Sn.

¶ The current flows perpendicular to c-axis of the crystal.

** Composition is not stated. Possibly: Constantan = 60Cu, 40Ni. German silver between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn. Manganin = 84Cu, 12Mn, 4Ni. Nickelin = 75 to 55Cu, 18 to 32Ni, 0 to 20Zn. Piano wire = 98.89Fe, 0.57C, 0.09Si, 0.01S, 0.02P, 0.42Mn.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Aalderink, *18*, **15**: 321; 10. (2) Adams and Johnston, *12*, **33**: 534; 12. Johnston and Adams, *12*, **31**: 501; 11. (3) Agricola, *Diss.*, Erlangen, 1902. (4) Barker, *2*, **31**: 321; 10. (5) Barrett, *3*, **49**: 309; 00. (6) Battelli, *Mem. accad. Torino*, **36**: 487; 85. *23*, **5**: 1137; 87. *59*, **21**: 228; 87. **22**: 157; 87. (7) Beck, *242*, **55**: 103, 470; 10. (8) Becquerel, *6*, **8**: 389; 66. (9) Berg, *3*, **32**: 447; 10.

(10) Bernoulli, *3*, **33**: 690; 10. *200*, **9**: 270; 12. (11) Bidwell, *2*, **3**: 204; 14. **10**: 756; 17. **19**: 447; 22. **23**: 357; 24. (12) Bidwell, *5*, **73**: 413; 04. (13) Bordoni, *59*, **2**: 245; 11. (14) Borelius, *3*, **52**: 398; 17. **53**: 615; 17. **56**: 388; 18. (15) Borelius and Gunneson, *3*, **65**: 520; 21. (16) Borelius and Lindh, *3*, **51**: 607; 16. **53**: 97; 17. (17) Bridgman, *65*, **53**: 269; 18. **61**: 101; 26. *2*, **9**: 269; 17. (18) Broniewski, *6*, **25**: 5; 12. *74*, **7**: 341; 10. *34*, **150**: 1754; 10. **152**: 85; 11. **156**: 1983; 13. (19) Broniewski and Hackspill, *34*, **153**: 814; 11. *6*, **29**: 455; 14.

(20) Brown and Shuddemagen, *2*, **5**: 385; 15. (21) Burgess and Crowe, *31A*, **10**: 315; 14. (22) Burgess and Scott, *31A*, **14**: 15; 16. (23) Campbell, *140*, **94**: 268; 16. (24) Caswell, *2*, **33**: 379; 11. **7**: 269; 16. **12**: 231; 18. (25) Cermak, *3*, **24**: 351; 07. **26**: 521; 08. **33**: 1195; 10. (26) Cermak and Schmidt, *3*, **36**: 575; 11. (27) Coblentz, *31A*, **6**: 107; 09. **7**: 197; 10. (28) Darling and Rinaldi, *67*, **36**: 281; 24. (29) Day and Sosman, *12*, **179**: 93; 10.

(30) des Coudres, *8*, **43**: 673; 91. (31) Dewar and Fleming, *3*, **40**: 95; 95. *cf.* Dickson, *174*, **47**: 737; 11. (32) Dupuy and Portevin, *34*, **155**: 1082; 12. *74*, **12**: 657; 15. (33) Englisch, *8*, **50**: 88; 93. (33.1) Erhard, *8*, **14**: 504; 81. (34) Feussner and St. Lindeck, *89*, **2**: 501; 95. (35) Fischer and Pfleiderer, *95*, **13**: 237; 21. (35.1) Fischer and Pfleiderer, *523*, **4**: 440; 19. (36) Forsythe, W. E., Nela Park Laboratory, Cleveland, Ohio, *0*. (37) Fuller, *78*, **27**: 241; 15. (38) Gehlhoff and Neumeier, *88*, **15**: 876; 13. (39) Geibel, *93*, **69**: 38; 11. **70**: 240; 11.

(40) Gottstein, *8*, **43**: 1079; 14. (41) Haken, *8*, **32**: 291; 10. (42) Haga, *8*, **28**: 179; 86. (43) Hall, Campbell, Serviss and Churchill, *65*, **42**: 597; 07. (44) Hirsch, *78*, **20**: 57; 11. (45) Holborn and Day, *8*, **2**: 505; 00. *12*, **10**: 171; 00. *76*, **1899**: 691. (46) Holborn and Wien, *8*, **47**: 107; 92. (46.1) Holmes, R. M., Cornell Univ., *0*. (47) Hunter and Bacon, *78*, **36**: 323; 19. (48) Hutchins, *12*, **48**: 226; 94. (49) Ingersoll, *2*, **16**: 126; 20.

(50) Jahn, *8*, **34**: 755; 88. (51) Jordan, *3*, **21**: 454; 11. (52) Koenigsberger and Weiss, *8*, **35**: 1; 11. (53) La Rosa, *59*, **12**: 284; 16. (54) Laws, *3*, **7**: 560; 04. (55) Lecher, *8*, **19**: 853; 06. **20**: 480; 06. (56) Ledoux, *34*, **155**: 35; 12. (57) LeRoux, *6*, **10**: 201; 67. (57.1) Morugina, *97*, **7**: 486; 26. (58) Nettleton, *5*, **29**: 59; 16. (59) Noll, *8*, **53**: 874; 94.

(60) Norsa, *34*, **155**: 348; 12. (61) Northrup, *33*, **9**: 45; 13. **15**: 193; 16. (62) Onnes and Holst, *64P*, **17**: 760; 17. (63) Oosterhuis, *18*, **2**: 7; 12. (64) Pécheux, *34*, **139**: 1202; 04. **147**: 532; 08. **148**: 1041; 09. **149**: 1062; 09. **167**: 487; 18. (65) Pelabon, *16*, **13**: 169; 20. *34*, **176**: 1305; 23. (66) Reichardt, *8*, **6**: 832; 01. (67) Riecke, *Lehrbuch der experimental Physik*, II: 345; 96. (68) Rohn, *95*, **16**: 297; 24. (69) Rudolfi, *93*, **67**: 65; 10.

(70) Schoute, *18*, **12**: 175; 07. (71) Sedström, *8*, **59**: 134; 19. *95*, **13**: 155; 21. (72) Shearer, *2*, **34**: 238; 12. (73) Siebel, *8*, **60**: 260; 19. (74) Siegel, *8*, **38**: 588; 12. (75) Smith, *2*, **32**: 178; 11. **19**: 285; 22. **22**: 58; 23. (75.1) Sosman, *12*, **30**: 1; 10. (76) Steele, *3*, **37**: 218; 94. (77) Swisher, *2*, **10**: 601; 17. (78) Wagner, *8*, **27**: 955; 08. (79) Wick, *2*, **25**: 382; 07.

(80) Wietzel, *8*, **43**: 605; 14. (81) Worthing, *2*, **7**: 497; 16.

ELECTRICAL CONDUCTIVITY OF AQUEOUS SOLUTIONS

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INTRODUCTION

Abbreviations, Symbols and Units

κ Specific conductance in $ohm^{-1}\ cm^{-1}$.

C Concentration in milliformula-weights per l of solution at the temperature t, unless otherwise indicated.

$\Lambda = 10^6\kappa/C$.

The unit of specific conductance is the reciprocal ohm and it is assumed that the standardizing solutions shown in the tables below have the specific conductances there given. To bring the older data into harmony with these values, the authors' conductance values have been increased by the appropiate amount as indicated in column 5 of Table 1.

Abréviations, symboles et unités

κ Conductibilité spécifique en $ohm^{-1}\ cm^{-1}$.

C Concentration en millimolécule grammes pour l de solution à la température t, à moins d'une autre indication.

$\Lambda = 10^6\kappa/C$.

L'unité de conductibilité spécifique est l'ohm réciproque et il a été admis que les solutions étalons données dans les tables ci-dessous ont les conductibilités spécifiques mentionnées à cette place. Pour mettre en harmonie avec ces valeurs les données plus anciennes, les valeurs de conductibilité données par les auteurs ont été augmentées d'une quantité appropriée, comme cela est indiqué dans la colonne 5 de la Table 1.

Abkürzungen, Symbole und Einheiten

κ Spezifische Leitfähigkeit in $Ohm^{-1}\ cm^{-1}$.

C Konzentration in Milligrammformel-Gewicht für ein l der Lösung bei der Temperatur t, wenn nichts anderes angegeben.

$\Lambda = 10^6\kappa/C$.

Die Einheit der spezifischen Leitfähigkeit ist das reziproke Ohm. Es wird angenommen, dass die Lösungen, welche zur Bestimmung der Widerstands-Kapazität den Gefässen dienten, den spezifischen Leitfähigkeit haben, welcher in den unteren Tabellen angegeben ist. Um ältere Daten mit diesen in Übereinstimmung zu bringen, werden die Leitfähigkeitswerte der Autoren um einen entsprechenden Anteil erhöht, wie es in der Kolonne 5 der Tafel 1 angegeben ist.

Abbreviazioni, simboli, e unità

κ Conduttura specifica in $ohm^{-1}\ cm^{-1}$.

C Concentrazione in milliformula-grammo per l di soluzione a temperatura t, a meno che non venga altrimenti indicato.

$\Lambda = 10^6\kappa/C$.

L'unità della conducibilità specifica è il reciproco dell' ohm; si suppone inoltre che le soluzioni titolate di confronto che figurano nelle tabelle più sotto hanno la conducibilità specifica ivi indicata. Per poter mettere d'accordo con questi i valori più vecchi, i valori datdagli autori sono stati accrei sciuti nel rapporto dovuto, come è indicato nella colonna 5 della Tabella 1.

SOLUTIONS FOR DETERMINING CELL CONSTANTS (199)

TABLE 1.—KOHLRAUSCH SOLUTIONS

The values given below have the following significance: Col. 2, grams of KCl per 1000 g H_2O, weights in air (d = 0.0012). Col. 3, temperature of measurement. Col. 4, specific conductance ohm^{-1} cm^{-1}. Col. 5, % difference, Col. 4 value minus the older Kohlrausch value.

1	2	3	4	5
Solution number	g KCl* / kg H_2O	t, °C	κ (I. C. T. value)	Corr., %
1	76.9153	0	0.6531	0.150
		18	.098116	.108
		25	.111687	.101
2	7.49313	0	.007141 6	.118
		18	.011184 6	.048
		25	.012876 5	.027
3	0.74756	0	.007742 2	.229
		18	.0012223 8	.214
		25	.0014103 7	.186
4	76.925	18	.09812 8	.145
5	7.4945	18	.011187 1	.145
6	0.74766	18	.0012225 2	.145
7	Max., H_2SO_4	25	0.8242	0.18

TABLE 2.—PARKER SOLUTIONS

$\kappa = A + 10^{-3}Bt + 10^{-6}Ct^2$

g KCl/kg H_2O*	76.6276	7.47896	0.746253
d, g/cm^3, 0°C	1.04804	1.004887	1.000372
t, °C	Values of κ, ohm^{-1} cm^{-1}		
0	0.065098	0.007129 5	0.0007728 4
5	.073876	.008205 5	.0008920 3
10	.082886	.009315 8	.0010151 3
15	.092132	.010460 3	.0011421 5
18	.097790	.011163 6	.0012202 3

TABLE 2.—(*Continued*)

g KCl/kg H_2O*	76.6276	7.47896	0.746253
d, g/cm^3, 0°C	1.04804	1.004887	1.000372
t, °C	Values of κ, ohm^{-1} cm^{-1}		
20	0.101607	0.011639 3	0.0012730 7
25	.111322	.012852 4	.0014078 9
30	.121267	.014099 6	.0015466 1
A =	0.065098	0.007129 5	0.0007728 4
B =	1.7319	2.1178	2.3448
C =	4.681	6.850	7.816

* In air (d = 0.0012), brass weights.

IONIC CONDUCTIVITY

TABLE 3.—ION CONDUCTANCES AT 18°C

Based upon I. C. T. atomic weights (*v.* Vol. I, p. 43) and upon the I. C. T. cell-constant values (Table 1 *supra*). Ion conductances not given here may be obtained by subtracting Λ_H (resp. Λ_{OH}) from the Λ_0 values given in the tables beginning on p. 259.

Ion	Λ	$\frac{1}{\Lambda}\left(\frac{d\Lambda}{dt}\right)_{18}$	Ion	Λ	$\frac{1}{\Lambda}\left(\frac{d\Lambda}{dt}\right)_{18}$
H.....	315.2	0.01573	OH.....	173.8	0.018
Cs.....	67.46	.0212	Cl.....	65.24	.0216
K.....	64.20	.0217	Br.....	67.31	.0215
NH_4.....	64.3	.0222	I.....	66.25	.0213
Na.....	43.16	.0244	NO_3.....	61.62	.0205
Li.....	33.02	.0265	ClO_3.....	54.87	.0215
Tl.....	65.3	.0215	BrO_3.....	47.6	
Ag.....	53.8	.0229	IO_3.....	33.78	.0214
$\frac{1}{2}$Ca.....	51	.0247	$C_2H_3O_2$....	35	.0238
$\frac{1}{2}$Mg.....	45	.0256	$\frac{1}{2}C_2O_4$.....	61	.0231
$\frac{1}{2}$Ba.....	55	.0239	$\frac{1}{2}SO_4$.....	68	.0227
$\frac{1}{2}$Pb.....	61	.0240	$\frac{1}{2}CrO_4$.....	72	

SOLUTIONS OF SALTS AND OF ALL INORGANIC STRONG ELECTROLYTES

CONTENTS

PART I.—Neutral halides, nitrates and sulfates.
PART II.—All other salts and strong electrolytes.

MATIÈRES

Sec. 1.—Halogénures, nitrates et sulfates neutres.
Sec. II.—Tous les autres sels et les électrolytes forts.

INHALTSVERZEICHNIS

Abschnitt I.—Neutrale Halogenide, Nitrate und Sulfate.
Abschnitt II.—Alle anderen Salze und starken Elektrolyte.

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PART I. CONDUCTIVITY OF NEUTRAL HALIDES, NITRATES AND SULFATES

EDWARD W. WASHBURN AND ALFONS KLEMENC

CONTENTS

Table 1.—Values of C up to 0.5.
Table 2.—Values of C from 0.5 to 1000.
Table 3.—Values of C above 1000.

In each table the salts are grouped according to the anion in the order F, Cl, Br, I, SO_4, NO_3 and under a given anion the cations follow the standard arrangement (*v.* Vol. III, p. viii).

MATIÈRES

Table 1.—Valeurs de C jusqu'à 0,5.
Table 2.—Valeurs de C de 0,5 à 1000.
Table 3.—Valeurs de C au dessus de 1000.

Dans chaque table les sels sont groupés en accord avec l'anion dans l'ordre F, Cl, Br, I, SO_4, NO_3 et sous un anion donné, les cations suivent l'arrangement type (*v.* Vol. III, p. viii).

INHALTSVERZEICHNIS

Tabelle 1.—Werte von C bis 0,5.
Tabelle 2.—Werte von C von 0,5 bis zu 1000.
Tabelle 3.—Werte von C über 1000.

In jeder Tabelle sind die Salze in der Reihenfolge ihrer Anionen angeordnet; F, Cl, Br, I, SO_4, NO_3. Unter den gegebenen Anionen folgen die Kationen in der Standardanordnung (*v.* Bd. III, S. viii).

INDICE

Tabella 1.—Valori di C fino a 0,5.
Tabella 2.—Valori di C da 0,5 a 1000.
Tabella 3.—Valori di C sopra 1000.

In ciascuna tabella i sali sono raggruppati secondo l'anione nell'ordine F, Cl, Br, I, SO_4, NO_3 e per un dato anione i cationi seguono l'ordinamento tipo (*v.* Vol. III, p. viii).

TABLE 1.—VALUES OF C UP TO 0.5

For literature references, *v.* Table 2

F

TlF, 18°	
C	$10^6\kappa/C$
0.1	114.40
0.2	114.66

NaF, 18°	
0.1	89.10
0.2	88.81

KF, 18°	
0.1	110.02
0.2	109.79

Cl

NH_4Cl, 18°	
0.1	129.3
0.2	128.9

$(C_2H_5)_4NCl$, 25°	
0.01	109.139
0.05	108.933
0.07	108.837
0.1	108.692
0.2	108.281

$\frac{1}{3}InCl_3$, 25°	
0.3	225

TlCl, 18°	
0.1	130.15
0.2	129.82

$\frac{1}{2}CaCl_2$, 18°	
0.1	115.01
0.2	114.39

$\frac{1}{2}SrCl_2$, 18°	
0.1	(118.5)
0.2	(117.4)

LiCl, 18°	
0.1	97.82
0.2	97.53

NaCl, 18°	
0.1	107.88
0.2	107.60

KCl, 18°	
0.01	129.379
0.02	129.317
0.05	129.126
0.07	129.003
0.10	128.836
0.20	128.483
100°	
0.2	402.6

RbCl, 18°	
C	$10^6\kappa/C$
0.1	132.1

CsCl, 18°	
0.1	132.0
0.2	131.7

Br

$(CH_3)_4NBr$, 25°	
0.01	124.263
0.05	123.958
0.07	123.807
0.1	123.586
0.2	123.010

$\frac{1}{2}RaBr_2$, 18°	
0.1	123.9
0.2	122.9

KBr, 18°	
0.1	130.86
0.2	130.57

I

$(C_3H_7)_4NI$, 25°	
C	$10^6\kappa/C$
0.01	99.649
0.05	99.492
0.07	99.378
0.1	99.307
0.2	98.990

KI, 18°	
0.1	129.50
0.2	129.24

SO_4

$\frac{1}{2}(NH_4)_2SO_4$, 18°	
0.1	130
0.2	128

$\frac{1}{2}ZnSO_4$, 18°	
0.1	109.6
0.2	107.6

$\frac{1}{2}CdSO_4$, 18°	
0.1	109.69
0.2	107.45

$\frac{1}{2}CuSO_4$, 18°	
0.1	109.80
0.2	107.80

$\frac{1}{2}MgSO_4$, 18°	
0.1	109.6
0.2	107.8

$\frac{1}{2}CaSO_4$	
C	$10^6\kappa/C$
18°	
0.1	115.5
0.2	114.0
25°	
0.1	136.5
0.2	133.1

$\frac{1}{2}Na_2SO_4$, 18°	
0.1	109.7
0.2	108.8

$\frac{1}{2}K_2SO_4$, 18°	
0.1	130.5
0.2	129.8

NO_3

NH_4NO_3, 18°	
0.1	(125.9)
0.2	(125.8)

$\frac{1}{2}Pb(NO_3)_2$, 18°	
0.1	120.59
0.2	119.80

$TlNO_3$, 18°	
0.1	126.59
0.2	126.26

$AgNO_3$, 18°	
0.1	114.85
0.2	114.40

$\frac{1}{2}Ca(NO_3)_2$, 18°	
0.1	111.75
0.2	111.03

$\frac{1}{2}Sr(NO_3)_2$, 18°	
0.1	111.58
0.2	110.91

$\frac{1}{2}Ba(NO_3)_2$, 18°	
0.1	115.16
0.2	114.49

$LiNO_3$, 18°	
0.1	94.17
0.2	93.86

$NaNO_3$, 18°	
0.1	104.30
0.2	103.94

KNO_3	
18°	
0.1	125.2
0.2	124.90
100°	
0.2	380.2

TABLE 2; *see* p. 232 to 238

TABLE 3.—VALUES OF C ABOVE 1000

For literature references, *v.* Table 2

F

NH_4F, 18°	
C	$10^6\kappa/C$
2 000	55.3
3 000	48.1
4 000	42.2

TlF, 18°	
2 000	62.8

AgF, 18°	
2 000	45.8
3 000	38.7

KF, 18°	
2 000	66.2
3 000	58.9
4 000	52.7
5 000	46.9
6 000	(42.0)

RbF, 18°	
2 000	71.3
3 000	64.2
4 000	57.5

Cl

NH_4Cl	
0°	
2 000	63.0
3 000	62.0
4 000	(60.0)
18°	
2 000	92.2
3 000	88.3
4 000	85.1
5 000	80.7

$C_6H_5NH_2HCl$, 25°	
2 000	44.8
3 000	33.0
4 000	23.0

$\frac{1}{4}SnCl_4$, 18°	
2 000	66.9
3 000	47.9
4 000	32.7

$\frac{1}{4}ThCl_4$, 18°	
2 000	44.33
3 000	36.3
4 000	29.81

$\frac{1}{3}InCl_3$, 25°	
3 000	10.2

$\frac{1}{2}ZnCl_2$	
18°	
2 000	39.5
3 000	29.6
4 000	22.9
5 000	18.4
6 000	15.2
7 000	12.9
8 000	10.60
11 520	5.36
15 370	2.36

$\frac{1}{2}ZnCl_2$.—(*Cont'd*)	
C	$10^6\kappa/C$
25°	
2 000	44.0
3 000	32.7
4 000	25.6
5 000	20.7
6 000	17.1
7 000	14.5
8 000	12.2
9 000	10.16
10 000	8.40
12 000	5.72
14 000	3.85
16 000	2.48
18 000	1.45
20 000	0.750
22 000	0.452

$\frac{1}{2}CdCl_2$	
18°	
2 000	14.17
3 000	10.02
4 000	7.06
5 000	4.85
6 500	3.33
7 760	2.27
9 180	1.45
25°	
2 000	16.06
3 000	11.42
4 000	8.26
5 000	5.74
6 492	4.10
7 745	2.85
9 160	1.86
100°	
2 220	31.3
3 420	21.1

$\frac{1}{2}CuCl_2$	
0°	
2 000	28.9
3 000	22.4
4 000	16.8
18°	
2 000	43.4
3 000	33.6
4 000	26.0

$\frac{1}{2}MnCl_2$	
18°	
2 000	45.3
3 000	35.7
4 000	28.17
5 000	21.8
6 000	16.30

$\frac{1}{2}MnCl_2$.—(*Cont'd*)	
C	$10^6\kappa/C$
25°	
2 000	51.7
3 000	41.3
4 000	32.4
5 000	24.9
6 000	20.0

$\frac{1}{2}FeCl_2$, 18°	
2 000	48.11
3 000	38.81
4 000	30.84
5 000	24.05
6 000	18.13

$\frac{1}{3}FeCl_3$	
0°	
2 000	24.2
3 000	17.8
4 000	13.0
18°	
2 000	37.5
3 000	27.8
4 000	20.9
5 000	15.90
6 000	12.40
8 000	6.20

$\frac{1}{2}CoCl_2$, 18°	
2 000	49.2
3 000	39.7
4 000	32.1
7 630	11.7

$\frac{1}{2}NiCl_2$, 18°	
2 000	50.6
3 000	41.0
4 000	33.33

$\frac{1}{3}CrCl_3$, Violet, 18°	
2 000	44.8
3 000	35.2

$\frac{1}{3}AlCl_3$	
0°	
2 000	27.3
3 000	21.5
4 000	16.4
5 000	12.5
6 000	8.57
18°	
2 000	44.5
3 000	34.2
4 000	27.16

$\frac{1}{2}BeCl_2$, 18°	
2 000	41.4
3 000	34.4
4 000	29.0

$\frac{1}{2}MgCl_2$	
0°	
2 000	33.0
3 000	27.7
8 034	7.49

Continued on p. 239

TABLE 2.—VALUES OF C FROM 0.5 TO 1000*

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
[F]; NH_4F	18									89.9	83.8	74.3	70.3	65.6	(95)
TlF	18	114.47	113.27	111.30	108.20	105.45	102.24	97.37	95.20	92.62	87.02	78.79	75.45	71.55	(99, 138)
	25		131.0	129.4	126.4	123.5	119.9								(72)
AgF	18									80.6	74.4	65.2	61.2	56.5	(95)
NaF	18	88.25	87.65	86.74	85.04	83.33	80.87	76.99	75.09	72.94	67.80	59.81	56.20	51.8	(138, 185)
KF	18	109.03	108.45	107.48	105.74	103.85	101.46	97.33	95.64	93.63	89.14	82.11	79.21	75.71	(95, 129, 185)
RbF	18										92.8	86.1	83.4	80.0	(99)
[Cl]; NH_4Cl	0		78.1	77.7	76.9	76.0	74.5	71.7	70.6	69.6	67.8	65.5	64.8	64.1	(109, 110, 131, 132)
	18	128.2	127.5	126.2	124.3	122.3	118.2	115.3		110.8		101.5		97.1	(133, 248)
	25		147.6	146.3	144.1	141.4	138.3	132.8	130.5	127.8	122	115	136.1†	107	(28, 34, 110, 248)
	50		227	225.7	222.5	218.6	(212.7)	202.3	198.6	194.5	185.1	171.9			(109)
	100			398.2		382.1	(378.8 at C = 12.5)								(180)
	156			600.1		571.9									(180)
	218			800		757									(180)
	306			1029		923	(826 at C = 30)								(180)
$C_7H_8O_2.HCl.2H_2O$	18					356.9	352.8	339.8	331.8	319.7	288.0	(*Also* at t = 19.8°C)			(224)
$(CH_3)_3NHCl$	18	104.5	103.8	(103.6 at C = 1.33)								(*Also* at t = 32, 35°C)			(172)
	25		121.4	120.2	117.9	115.8	113.1	108.6	106.7						(34, 172)
$C_3H_7NH_2HCl$	18	98.5	97.8	96.8	(95.9 at C = 3)										(172)
	25		114.7	113.6	112.1							(*Also* at t = 32, 35°C)			(172)
$C_6H_5NH_2HCl$	25									89.7	83.8	72.5	67.2	60.8	(244)
$(C_2H_5)_2NH_2Cl$	18	94.9	93.8	(93.0 at C = 3)											(172)
	25			110.0	(108.7 at C = 3)										(172)
$(C_3H_7)_2NH_2Cl$	18	90.1	89.2	(88.4)											(172)
	25	(105.9)	104.9	103.6								(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_3NHCl$	18	92.4	91.8	90.6											(172)
	25		107.3	106.2	(105.3 at C = 3)							(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_4NCl$	25	107.427	106.532												(11); *cf.* (28)
$(C_3H_7)_4NHCl$	18		86.5	85.3											(172)
	25		100.4	99.1	(98.1 at C = 3)							(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_2C_{16}H_{33}NHCl$	56	229	198	133	91.6	74.3	64.0								(220)
$C_{20}H_2N_3Cl$	0	49.4	49.7	50.6	Rosaniline hydrochloride										(56)
	25			92.6	91.7	88.3									(56)
$(C_6H_5CH_2)_3CH_3NCl$	18				79.5	77.5	74.4	(68.8)	(72.2 at C = 30)						(64)
$C_9H_{12}ClNO$	25	Hydroxyhydrindamine hydrochloride													(206)
$TiCl_3$															(98)
$ZrOCl_2$															(233, 256)
$\frac{1}{4}SnCl_4$	18											(217)		(122)	(99)
$\frac{1}{2}PbCl_2$	0		73.0	72.2	69.0	64.7	59.2								(109)
	18		118.98	115.7	109.1	102.0	93.1	79.1							(105, 185)
	25		138.5	134.4	126.7	118.1	107.5	91.2							(105, 185)
	50		219	205	193	179	160								(109)
$\frac{1}{4}ThCl_4$	18											61.0	57.7	54.0	(99)
$\frac{1}{3}InCl_3$	25	(101 at C = 3)					(50.6 at C = 30) (30.5 at C = 300)								(251)
TlCl	0	(81.9)	81.13	80.16	78.21		(77.411 at C = 6.7793 or satd. soln.)								(212)
	18	129.00	128.05	126.63	123.56	120.04	(118.30 at C = 12.78 or satd. soln.)								(138)
	25			(146)	142.9	138.8	(135.3 at C = 16.07 or satd. soln.)								(26)
$\frac{1}{2}ZnCl_2$	18									86.5	79.3	68.7	63.2	56.2	(95, 154)
	25											79.4	73.0	64.3	(154, 207)
$\frac{1}{2}CdCl_2$	0		64.1	60.4	54.9	50.3	45.1	37.5	34.8	31.8	25.9	17.9			(109)
	18		104.8	99.5	90.7	82.9	74.1	60.1	55.2	50.0	41.0	29.6	25.7	21.64	(84, 85, 273)
	25		120.5	116.2	105.5	95.7	84.2	68.5	63.1	57.4	47.0	34.2	29.7	24.9	(84, 85, 109, 273)
	50				159	142	125	101	92	83.5	67.4	47.8			(109)
	100	(95.9 at C = 192) (55.1 at C = 959)													(92)
$\frac{1}{2}HgCl_2$	18	(2.59 at C = 17.0) (1.51 at C = 75.4) (1.07 at C = 392)													(85)
	25	(3.38 at C = 16.9) (1.30 at C = 75.3) (1.25 at C = 391)													(85)
$\frac{1}{2}CuCl_2$	0			65.3	63.0	60.9	58.7	55.1	53.6	51.9	48.5	42.9	40.3	37.0	(109, 110)
	18									83.2	77.1	67.0	62.3	56.9	(48, 95)
	25			123.4	118.7	114.9	110.2	102.5	99.2	95.4	87.2	74.7	69.6	64.1	(109)
Ir and Pt	H_2IrCl_6, H_2PtCl_6, $(NH_4)_2PtCl_6$, K_2PtCl_6 (177.5), $PtCl_4$ (258)														
$\frac{1}{2}MnCl_2$	0		(61)	60.4	59.1	57.3	55.2	51.0	50.5	48.9	45.4	39.7	37.5	35.2	(109)
	18											66.4	61.8	57.4	(99)
	25			(118)	112.8	108.7	104.3	97.2	94.2	90.7	84.0	73.5	69.3	64.4	(109, 154)

* When the literature cited contains data at other temperatures, this is indicated thus: (*Also* at t = 32, 35°C). † At C = 30.

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
½$MnCl_2$.—(*Continued*)	50		198	194	186	179	170	158	152	146	131	107	96	94	(109)
½$FeCl_2$	18											69.4	65.5	60.6	(99)
⅓$FeCl_3$	0				136	100	75	59	57	55.2	50.5	41.8	38.0	33.6	(109)
	18											66.5	60.4	53.1	(99)
½$CoCl_2$	18												65.6	60.8	(99, 165); *cf.* (103.5)
½$NiCl_2$	18											70.8	66.8	62.1	(99)
⅓$CrCl_3$, violet	18										75.4	68.6	(64.5)	58.9	(99)
$CrCl_3.6H_2O$, green															(15, 16, 98)
⅓$CrCl_3$, blue	25			(159.9)	143.1	131.1	120.0	106.9	102.6	98.6					(15)
UO_2Cl_2	0	(*Also* at t = 12.5, 25, 35, 50, 65° C)													(109)
	25														(62, 109)
$VOCl_3$															(2)
⅓$AlCl_3$	0			65.8	62.0	59.0	56.1	51.8	50.3	48.7	45.0	39.6	37.3	34.4	(109, 110)
	18											65.0	61.0	56.2	(99)
	25		144	136	125	117.9	110.0	99.7	96.2	92.2	84.4	73.7	69.6		(15, 109)
	50				204	191	178	161	154	147	134	115	107		(109)
⅓$ScCl_3$	25		141.5	133.5	123.1	115.8	108.4	98.4							(19)
⅓YCl_3	25	131.5	129.4	126.2	120.4	115.2	108.9	100.3	96.9						(19, 146)
⅓$LaCl_3$	25		131.7	127.6	121.6	115.9	109.7	101.3	98.1	94.6					(8, 19, 146, 177)
⅓$CeCl_2$	25		134.4	130.7	124.1	118.4	111.9	102.9	(99.2)						(8, 19)
⅓$PrCl_3$	25		139.6	135.8	129.3	124.2	118.4	107.7							(8, 19)
⅓$NdCl_3$	25		138.1	134.2	128.4	115.8	108.5								(19)
	25		133.6	129.4	123.0	117.3	109.6								(8)
⅓$SaCl_3$	25		134.0	129.8	122.8	115.9	107.5								(8, 224)
⅓$YbCl_3$	25		140.3	136.0	128.4	121.4	113.3								(221)
½$BeCl_2$	18											58.4	54.2	51.6	(99)
½$MgCl_2$	0				67.7	65.7	63.4	59.4	57.6	55.2	51.8	46.0	43.6	40.6	(109, 110, 130, 131, 132)
	25		127.2	124.4	120.3	116.6	112.2	(106)	(103)	(101)	(94)	(84)	(79.2)	73.5	(130, 131, 132, 260)
½$CaCl_2$	0		70.7	68.9	66.4	64.1	61.6	57.9	56.4	54.9	51.8	47.4	45.7	43.4	(109, 110, 135)
	18	113.18	111.80	109.92	106.55	103.23	99.24	93.16	90.75	88.07	82.68	74.82	71.42	67.45	(133)
	25													77.54	(135)
	50				191	185	178.6	166.4	161.0	154.8	142.6	126.8			(82, 109)
	100													201	(82, 92); *cf.* p. 240
½$SrCl_2$	0		73	71.5	68.9	66.6	64.0	59.9	58.3	56.6	53.2	48.4	46.5	44.3	(109, 110, 130, 131, 132)
	18	115.8	114.3	112.3	108.8	105.3	101.2	95.2	92.9	90.4	85.1	76.1	72.3	67.9	(130, 131, 132, 133)
	25		132	129	123.8	119.5	114.8	108.5	106.0	103.2	97.2	87.7	83.6	78.4	(109, 130, 131, 132)
	40						(110.0 at C = 654)								(130, 131, 132)
	100										270	(234)	(219)	202	(92)
½$BaCl_2$	0	72.3	71.6	70.4	68.2	66.3	63.9	60.1	58.5	56.8	53.7	49.6	48.1	46.2	(60, 109, 116, 130, 131, 132, 185, 274)
	18	116.85	115.44	113.6	110.0	106.52	102.39	95.91	93.6	90.65	85.23	77.18	74.40	70.04	(48, 133)
	25		134.5	131.7	127.7	123.7	119.2	111.7	108.6	105.3	98.6	88.8	85.1	80.5	(109, 128, 130, 131, 132, 146)
	50		212	205	196	188.3	179.8	167.3	162.6	157.4	147.1	130.3	124.4	117.6	(109, 110, 140)
	100						(235 at C = 400)				261			197.8	(92)
LiCl	0		59.03	58.91	57.89	56.68	55.30	53.14		50.86	48.31	43.99	42.10	39.85	(103, 131, 132, 265)
	18	96.87	96.20	95.30	93.62	91.84	89.62	85.85		82.76	77.69	70.50		63.18	(137)
	25		114.0	112.7	109.1	107.0	104.3	99.7	97.8	95.5	89.9	81.0	77.3	73.1	(81, 109, 195, 235)
	50		178.3	175.9	172.1	168.0	163.0	155.1		143.2	139.9	125.5	119.0	112.3	(103, 109)
	100									288.0	265.5	237.2	216.8	199.3	(92, 103)
NaCl	0		65.8	65.2	64.2	63.2	61.7	59.5	58.7	57.7	55.6	51.8	49.9	47.5	(130, 131, 132, 185)
	18	106.95	106.27	105.31	103.54	101.72	99.40	95.51		91.82	87.53	80.76		74.19	(137)
	25	125.0	124.12	123.08	120.88	118.68	115.85	111.08	109.01	106.66	101.55	93.31			(135, 156, 185)
	50		195.3	193.6	190.1	185.6	179.9	170.8	167.1	163.4	155.6	141.9			(109)
	100	354.9	352.5	348.5	341.9	335.0	325.4	309.7	303.2	295.6	287.9	274.4	263.6	247.5	(92, 182, 263)
	140	491		481		461	(411 at C = 80)			403.5					(180)
	156	545		534		511	(540.5 at C = 80)			441.5					(180)
	218	741		723		686	(501 at C = 80)								(180)
	281	922		895		820	(674 at C = 80)								(180)
	306	1003		955		860	(680 at C = 80)								(180)

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
KCl	0	80.0	79.7	79.2	78.4	77.284	75.6	73.2	72.25	71.295	69.4	66.9	66.0	65.098	(130, 131, 132, 199, 274)
	18	127.86	127.07	126.05	124.15	122.18	119.72	115.51	113.7	111.79	107.74	102.25	100.3	98.08	(137, 199, 269)
	25		147.4	146.3	143.8	141.180	138.04	133.1	131.03	128.620	123.9	117.2	114.6	111.861	(136, 156, 199)
	50		226.0	224.0	219.1	215.1	210.1	201.5		194.3	187.9	173.3			(109, 182)
	75					295.0				264.4					(180)
	100	399.6	396.6	392.59	385.1	376.6	366.1	350.2	343.8	335.6		(341.1 at C = 80)			(180, 263)
	128					465.5				414.6					(180)
	140			534		(455 at C = 80)				446					(180)
	156			588		560	(498 at C = 80)			489					(180)
	218			780		742	(639 at C = 80)								(180)
	281			930		874	(723 at C = 80)								(180)
	306			1008		910	(720 at C = 80)								(180)
$\frac{1}{3}K_3W_2Cl_9$	1				77.1	73.4	68.9	62.6	60.1	57.4					(51)
RbCl	6											81.6		79.8	(49)
	18		130.1			125.2					114.8	111.1	106.2	102.0	(49, 94, 95, 125, 126, 127, 128, 129, 133)
	25		149.9	149.7	147.4	144.9	141	(139 at C = 30)							(22, 28)
CsCl	0										70.8	68.3	67.8	67.4	(207)
	18	131.05	130.35	129.20	127.15	124.89			115.5	113.28	108.6	102.7	100.8	98.8	(93, 138, 185)
	25		152.0	150.3	147.7	145.0	141.3	(138.7 at C = 30)							(22, 28)
	50											(167)	162.2	156.4	(207)
[Br]; NH_4Br	0*			1.153	1.140	1.127	1.107	1.073	1.059	1.043	1.016	**1.000**			(109)
	18							117.8	116.2	114.3	110.0	104.8	103.3	101.7	(82, 93)
$(CH_3)_4NBr$	25	121.88	120.00												(11)
$(C_6H_5CH_2)_3NHBr$	18				81.5	79.1	75.2								(64, 66)
	25					(90.3 at C = 14.4)									(66)
$\frac{1}{3}InBr_3$	18									53.9	46.8	37.0	33.1	28.74	(93, 95, 96, 97, 99)
$\frac{1}{2}ZnBr_2$	25						(100.1 at C = 90)					83.9	79.7	74.3	(207)
$\frac{1}{2}CdBr_2$	0		64.0	59.3	52.2	46.5	40.3	32.4	29.8	27.1	21.8	15.2			(109)
	18		103.7	97.0	85.9	75.8	65.7	52.4	47.9	43.2	35.1	25.2	22.0	18.8	(84, 85, 273)
	25		120	110.9	98.3	87.9	76.9	61.4	56.0	50.3	40.2	29.00	25.4	21.7	(84, 85, 109, 273)
	50		187	173	153	135	117	94.5	86.3	77.6	62.0	43.6	37.6	31.7	(207)
$\frac{1}{2}HgBr_2$	18			(1.29 at C = 12.4)				(1.10 at C = 23.6)							(85)
	25			(1.63 at C = 12.4)				(1.34 at C = 23.6)							(85)
$\frac{1}{2}CuBr_2$	0		68	66.8	64.2	62.3	60.2	56.7	55.4	53.9	50.2	44.6	42.5	40.0	(109)
	25		128	125	122	119	114	107	104	100	92	81	77	72	(109)
$PtBr_4$															(171)
$\frac{1}{2}MnBr_2$	18											72.3	68.8	64.7	(99)
	25		124.5	122.2	117.7	112.8	107.5								(3)
$\frac{1}{2}FeBr_2$	18											72.2	68.8	64.3	(99)
$\frac{1}{2}CoBr_2$	0			64.3	63.9	62.7	60.6	57.0	55.7	54.2	51.5	46.7			(109)
	18											73.2	69.7	65.5	(99)
	25			123.1	119.7	116.3	112.3	105.3	102.5	99.3	92.8	82.7			(109)
	50				186	180	173	162	157	152	142	127			(109)
$\frac{1}{2}NiBr_2$	18									86.2	81.0	73.3	69.9	65.8	(99)
$\frac{1}{3}CrBr_3$; violet	18									87.6	81.6	72.7	68.6	63.8	(99)
$\frac{1}{3}AlBr_3$	0		67.4	65.6	63.0	60.8	58.7	55.4	54.1	52.6	49.5	44.5			(115)
	25		138.1	132.2	124.1	118.1	112.1	103.9	100.8	97.3	90.6	80.9	76.2	70.6	(115)
$\frac{1}{2}MgBr_2$	0		68.9	67.6	65.6	63.8	61.6	58.6	57.4	55.9	52.9	47.4	45.1	42.6	(109)
	18							94.4	91.8	89.0	83.0	73.4	69.6	65.2	(93)
	25		128.3	125.0	120.5	117.2	113.7	107.8	105.1	102.0	95.4	83.6	78.6	72.9	(109)
	50				188	182	174	162	156	151	142	134			(109)
$\frac{1}{2}CaBr_2$	18							97.9	96.0	92.9	87.0	78.9	75.6	71.7	(93)
$\frac{1}{2}SrBr_2$	18							100.3	97.1	93.7	87.3	78.4	74.9	71.0	(93)
$\frac{1}{2}BaBr_2$	0		70.9	69.8	67.9	66.1	64.0	60.8	59.6	58.2	55.0	50.9	49.4	47.8	(109)
	18							98.1	95.9	93.5	88.4	80.4	77.3	73.8	(93)
	25		133.2	131.5	127.9	123.8	118.9	111.9	109.3	106.4	100.4	91.2	87.3	83.1	(109)
	50			205	200	195	187	174	169	164	153				(109)
$\frac{1}{2}RaBr_2$	18	121.1	119.6	117.2	113.5†	110.1	105.8	99.5†							(134)

* Relative to Λ_{500} = 1. † For temp. coeff., *see* (134).

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
LiBr	0		61.2	61.0	60.5	59.3	57.4	55.1	54.3	53.4	51.4	47.5	45.6	43.4	(109, 110)
	18							87.8	86.1	84.3	80.8	74.1	71.0	67.2	(93)
NaBr	18							99.0	97.6	95.9	91.7	84.5	81.7	78.0	(93)
	25	126.9	126.2	125.0	122.8	120.5	117.8	113.2	111.3	109.1	104.4	97			(109, 156, 195)
	50	1.0500	1.0452	1.0395	1.022	**1.000**	0.9697	0.9265	0.8880	0.8410	0.7570	(Relative to Λ_{10} = 1)			(109)
KBr	0								(74.7)	73.6	71.1	69.1	68.8	68.5	(245)
	18	129.86	129.10	128.04	126.13	124.13	121.61	117.53		113.98	110.17	105.06	103.22	101.2	(48, 82, 93, 94, 138)
	25	150.8	149.9	148.5	146.1	143.5	140.5	135.7	133.6	131.4	127	123			(109, 156, 205)
	50	(234)	233.8	231.5	227.7	223.1	217.4	208.8		201.1	192.5	180.4	175.8	170.6	(82, 109)
RbBr	6											82.7	82.1	81.2	(49)
	18	(Relative to Λ_{500} = 1)								1.0860	1.0465	**1.000**		0.9674	(95)
	25	(Relative to Λ_{500} = 1)				1.476	1.424	1.345	1.309	1.265	1.161	**1**			(57)
CsBr	18											106.3	104.2	101.7	(99)
[I]; NH_4I	18							117.9	116.6	114.9	110.9	105.9	104.6	103.4	(93)
$(C_3H_7)_4NI$	25	98.36	97.65												(11)
$(C_2H_5)_4NI$	0		56.7	56.2		53.6				40.2					(109)
	25	106.7	105.4	104.1	101.8	99.2	95.4	88.8	86.1	83.0					(109, 203)
	35		127	126	124	121	116	107	102	98					(109)
$(CH_3)_4NI$	25		123.5	121.2	116.8	112.4	107.1	98.7	95.2	91.2					(100)
$\frac{1}{2}ZnI_2$	25			(105 at C = 60)								87.5	83.6	78.6	(207)
$\frac{1}{2}CdI_2$	0		57.7	51.7	43.9	37.5	30.9	22.7	20.2	17.7	13.8	10.8			(109)
CdI_2															(35)
$\frac{1}{2}CdI_2$	18		98	91.2	76.6	64.7	53.3	39.3	34.5	29.7	23.5	18.3	16.8	15.32	(84, 85, 273)
	25		111	100.2	89.5	77.2	63.9	47.3	41.5	35.9	27.9	21.4	19.7	17.9	(84, 85, 109, 273)
	50		176	161	139	121	102	76	66.5	58.0	44.5	32.8			(109)
	100		(79 at C = 192) (42.2 at C = 959)												(92)
$\frac{1}{2}MgI_2$	18							94.5		89.7	84.1	75.6	72.4	68.6	(93)
$\frac{1}{2}CaI_2$	18							99.4	97.3	94.7	89.5	82.1	79.0	75.4	(93)
$\frac{1}{2}SrI_2$	18							98.9	96.5	93.8	88.6	81.5	78.6	75.1	(93)
$\frac{1}{2}BaI_2$	18							102.3	99.6	96.7	91.2	83.7	80.8	77.3	(93)
LiI	18							89.3	88.3	84.9	81.4	75.4	72.7	69.2	(93)
NaI	0		66.0	65.8	65.3	64.5	63.1	61.2	60.4	59.5	57.6	55.2			(109)
	18							97.6	96.0	94.2	90.1	84.0	81.6	78.5	(93)
	25		124.3	123.7	122.2	119.8	117.0	112.8	111.0	108.9	104.9	99.5	96.5	92.9	(109, 207)
	50			1.052	1.024	**1**	0.972	0.931	0.916	0.899	0.865	(Relative to Λ_{10} = 1)			(109)
KI	0		81.7	81.1	79.9	78.7	77.4	75.1	74.2	73.4	71.8	70.2	70.0	70.1	(109, 112, 245)
	18	128.71	127.99	126.96	125.07	123.19	120.83	117.01	115.42	113.78	110.43	106.07	104.72	103.39	(48, 93, 135, 138, 185)
	25		147.3	146.3	144.2	141.9	139.1	134.4	132.5	130.5	126.3	120.5			(25, 109, 110, 203)
	50		230	226	217.7	213.0	209.1	202.0	198.6	194.8					(109)
KI (satd. with I)	25		131	130	128	125.8	123.1	118.3	116.5	114.7					(25)
KI_3	25	113.0	112.0	110.9	108.6	106.4	103.7	99.7	(Corrected for solubility of I_2)						(25); *cf.* (35)
RbI	6				(83.8 at C = 400)								82.7	82.2	(49)
	18								(119.2)	117.1	113.0	108.3	106.9	105.4	(49, 95)
	30											133.7	131.5	128.9	(49)
[SO_4]; $\frac{1}{2}(NH_4)_2SO_4$	18	127	124.5	122.0	117.9	113.5	(107.4)	(98.9)	(95.7)	92.0	(84.9)	75.5	71.9	68.2	(94, 124, 202)
	25		143.4	141.5	137.7	133.1	126.8	115.9	111.8	107.8	99.1	87.1	82.7	77.9	(109, 124)
$ZrOSO_4$															(256)
$Zr(SO_4)_2$															(234, 256)
$\frac{1}{2}Tl_2SO_4$	18		127.35	124.2	118.4	112.3	104.55	92.7	88.0	83.1	73.8				(105, 185)
	25		147.8	144.2	137.3	130.0	120.9	107.1	102.0	96.0	85.0				(105, 185)
$\frac{1}{2}ZnSO_4$	0	63.6	60.3	56.4	50.4	45.4	39.7	33.4	31.4	29.4	25.5	20.9	18.9	16.3	(109, 116, 185)
	18	103.4	98.5	92.1	81.8	72.8	63.8	52.8	49.1	45.4	39.1	31.4	28.7	26.0	(133, 135)
	25		112	106	95	84.3	73.4	60.6	56.5	52.4	44.8	36.3	33.3	30.08	(109, 135)
	50		183	168	145	127	110	89	82	76	65.5	55.6			(109)
$\frac{1}{2}CdSO_4$	0	61.6	58.7	55.1	49.0	43.7	38.1	31.1	28.7	26.2	22.4	18.3	16.7	15.0	(116, 185)
	18	102.79	97.58	90.79	79.59	70.23	60.87	49.53	45.91	42.15	35.84	28.70	26.75	23.56	(85, 133)
	25		113.2	105.5	93.0	81.7	70.4	57.0	52.9	49.0	(41.8)	33.3	30.5	27.3	(85, 273)
$CuSO_4$	0	62.7	59.6	55.9	47.9	44.2	38.8	32.1	30.2	27.7	23.7	18.9	17.5	15.9	(109, 116, 274)
	18	103.42	98.42	91.81	80.87	71.64	62.32	51.09	47.38	43.79	37.61	30.72	28.25	25.74	(133, 135)

TABLE 2.—(*Continued*)

	°C	$C = 0.5$	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}CuSO_4$.—(*Continued*)	25		115.2	110.3	97.5	83.3	72.2	58.8	54.6	50.48	43.5	35.1	32.3	29.3	(89, 109, 135)
	50		182	166	142	123.0	106.0	85.6	79.0	72.4	61.0	49.9			(109)
$\frac{1}{2}Ag_2SO_4$	18		116.8	114.2	108.9	103.3	95.5								(65, 105)
	25		135.2	132.4	126.1	119.7	111.5								(105)
$AgC_2H_5SO_4$	25		101.1	100.2	97.8										(153)
$\frac{1}{2}MnSO_4$	0			56.9	50.4	45.4	40.3	33.6	31.5	29.2	24.9	19.8			(109)
	18											(30.0)	27.5	24.73	(124)
	25			107	93.9	84.0	74.0	60.8	56.4	52.1	44.5	35.5	32.4	29.00	(109, 124)
	50					104	87.2	81.1	74.7	63.1	47.9				(109)
$\frac{1}{2}FeSO_4$	18											30.8	28.5	25.8	(124)
	25				85.9	76.8	68.5					35.5	32.9	29.7	(124, 259)
$\frac{1}{2}CoSO_4$	0		58.8	54.4	48.4	43.6	38.7	32.1	29.8	27.5	23.6	18.9	17.3	15.7	(109)
	25		113.4	104.6	92.3	82.5	72.7	60.1	55.7	51.4	43.9	35.3	32.5	29.3	(109)
	50		181	(160)	(135)	(118)	104	88.6	83.1	77.4	66.2	50.8			(109)
$\frac{1}{2}NiSO_4$	18	102	94.4	88.4	78.3	69.8	61.1	50.3	47.1	43.8	37.9	30.6	28.1	25.40	(124, 135, 202); *cf.* (176.5)
	25			106.3	94.2	83.9	73.2	59.7	55.6	51.6	44.5	35.8	32.8	29.6	(109, 124); *cf.* (176.5)
	50			147	126	110	(97)	(82)	(77)	(72)	63.1	52.2			(109)
$\frac{1}{6}Cr_2(SO_4)_3$, violet	0		(59)	53.0	45.3	39.7	34.6	28.7	26.8	24.7	20.9	15.8	14.1	12.3	(109, 272)
	25		128	116.9	99.8	85.9	74.5								(260, 261, 262)
UO_2SO_4	0	(*Also* at t = 12.5, 25, 35, 50, 65°C)													(62, 109)
$VOSO_4$															(139)
$\frac{1}{6}Al_2(SO_4)_3$	25		107.0	95.0	78.9	67.3	57.2								(261)
$\frac{1}{6}Sc_2(SO_4)_3$	25		(65.7)	54.4	42.7	35.8	29.9	24.1	22.2	(Original values are lowered 5 %)					(19)
$\frac{1}{6}Y_2(SO_4)_3$	25		86.0	73.1	57.6	48.2	40.4	32.1	(29.4)						(19)
$\frac{1}{6}La_2(SO_4)_3$	0			39.8	(31.2)	26.3	(22.0)	17.2	15.8	14.4	12.1				(186)
	18			60.1	(48.0)	39.7	(33.1)	25.7	23.5	21.4	17.8				(186)
	25			67.9	(53.5)	44.6	(37.0)	28.7	26.3	23.9	19.8				(186)
$\frac{1}{6}Ce_2(SO_4)_3$	25		87.6	72.3	56.2	46.8	39.4	31.1	(28.4)						(19, 170)
$\frac{1}{6}Pr_2(SO_4)_3$	25		85.6	71.6	55.9	(46.9)	39.5	30.9	28.2	25.7	21.3	16.3			(19)
$\frac{1}{6}Nd_2(SO_4)_3$	25		83.1	71.3	57.2	47.7	39.6	31.2	28.7	26.1	21.7				(19, 113)
$\frac{1}{6}Sa_2(SO_4)_3$	25		88.7	74.7	58.8	48.8	40.8								(8, 19)
$\frac{1}{6}Gd_2(SO_4)_3$	25		87.6	74.1	59.0	49.2	41.7								(19)
$\frac{1}{6}Er_2(SO_4)_3$	25		96.1	82.7	66.5	56.3	47.5								(19)
$\frac{1}{6}Yb_2(SO_4)_3$	18			68.6	54			31.7		27.2	23.0				(50)
$\frac{1}{2}MgSO_4$	0	63.3	60.4	56.9	51.4	46.7	41.7	35.2	32.9	30.6	26.5	21.4	19.7	17.9	(60, 116, 185, 274)
	18	104.2	99.9	94.21	84.31	76.07	67.56	56.73	53.29	49.57	43.05	34.89	31.99	28.99	(70, 89, 133, 191)
	25	123.2	117.6	110.9	98.8	88.92	79.02	66.50	62.20	57.84	49.81	40.75	37.38	33.60	(89, 124, 135)
	50			168	147	132	116	97	91	84	73	58	53	48	(109)
	100*			302		223.2	189.8	151.3		129.4	110.4	(100.5 at C = 320)			(191)
	156†			377		240.7	194.8	148.8		125.9	109.0	(98.6 at C = 320)			(180)
	217.8			260		143	110.4	(88.4 at C = 40) (75.1 at C = 80) (62.4 at C = 160)							(180)
$\frac{1}{2}CaSO_4$	18	109.25	103.94	97.16	86.42	77.42	68.30	(62.94 at C = 29.5 or satd. soln.)							(89, 104, 133, 166)
	25	127.22	121.40	113.04	100.01	90.02	79.21	(72.3 at C = 30.5 or satd. soln.) (69.1 at C = 36.4)							(89)
	50	(159.8 at C = 4)		175.8		136.4	117.9	(107.5 at C = 30.0 or satd. soln.) (142.2 at C = 8)							(166)
	100	(257.7 at C = 4)		294.6		208.8	173.8	(166.6 at C = 23.3 or satd. soln.) (220.2 at C = 8)							(166)
	156			341	(280 at C = 4) (243 at C = 6.4 or satd. soln.—soluble anhydrite)										(166)
$\frac{1}{2}Li_2SO_4$	0			57.0	55.1	53.0	50.1	45.2	43.6	41.3	37.1	30.7	28.1	25.0	(109)
	18	97.57	96.14	94.31	90.70	86.75	81.94	74.48	71.36	67.97	60.86	50.38	46.22	41.22	(94, 99, 125, 126, 127, 128, 129, 133, 185)
Na_2SO_4	0‡		127.08	123.49	117.39	111.5	104.51	93.99	85.24	75.62					(211)
$\frac{1}{2}Na_2SO_4$	0		64.2			58.5		51.2							(60, 185)
	18	107.3	105.8	104.1	100.2	96.1	91.0	83.68	80.9	77.6	70.4	59.4	55.2	50.3	(4, 94, 99, 124, 125, 126, 127, 128, 129, 133, 185, 241)
	25			122.1	117.28	112.39	106.80	97.8	94.2	90.0	81.54				(185)
	50				187	178	169	152.9	147.0	140.5	122.3	107.4	99.6	91.1	(140)

* 212.2 at C = 12.5, 178.8 at C = 25, 159.8 at C = 40, 135.9 at C = 80, 116.4 at C = 160.

† 224.7 at C = 12.5, 179.8 at C = 25, 157.8 at C = 40, 132.9 at C = 80, 114.7 at C = 160.

‡ Concentrations are m(= millimole/kg H_2O) and conductance data are $10^6\kappa/m$.

TABLE 2.—(*Continued*)

	°C	$C = 0.5$	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}K_2SO_4$	0	79.4	78.8	77.4	74.6	72.1	68.9	63.7	61.6	59.4	55.1	49.2			(60, 109, 116, 185)
	18	128.3	126.7	124.4	120.1	115.6	110.1	101.84	98.4	94.82	87.80	78.30	75.0	71.50	(124, 133, 185, 191, 241)
	25			144.6	139.6	134.2	127.9	117.98	114.10	109.71	101.26	90.3	(96.02 at $C = 300$)		(26, 87, 185)
	100	(357.5 at $C = 12.5$)		40.09		364.7		311.6		285.6	(319.6 at $C = 40$)				(191)
	156			605		537	(454.4 at $C = 40$) (414.4 at $C = 80$)								(191)
	217.8			805		672	(545 at $C = 40$) (482 at $C = 80$)								(191)
	280.9			892		687	(519 at $C = 40$) (448 at $C = 80$)								(191)
	305.7			866		637	(466 at $C = 40$) (395 at $C = 80$)								(191)
$\frac{1}{2}Rb_2SO_4$	6											64.9	62.6	60.1	(49)
	18									103.5	95.9	85.8	82.1	78.2	(95)
	30											106.7	102.1	96.9	(49)
$[NO_3]$; NH_4NO_3	0		78.4	77.2	76.0	74.9	73.5	70.8	69.7	68.4	65.7	62.1	60.6	59.0	(109, 245)
	18		124.3	122.8	120.3	118.2	115.0	110.4	108.5	106.3	101.5	94.4	91.7	88.6	(70, 126)
	25		142	141.4	138.7	136.2	133.3	128.0	125.5	122.8	116.9	108.0			(109)
	50		218.7	215.3	211.2	207.1	201.8	192.8	188.4	184.9	174.7	159.2			(109)
	100									(324)	304	273	260	244	(207)
$C_9H_{12}N_2O_4$	25		Hydroxyhydrindamine nitrate												(217)
$\frac{1}{2}Pb(NO_3)_2$	0		(73.3)	71.34	67.93	64.71	60.42	53.27	50.28	47.04	40.55	31.8	28.0	24.3	(109, 212)
	18	117.94	116.00	113.41	108.56	103.44	96.89	86.28	82.05	77.18	67.29	53.15	47.80	41.97	(133, 154, 185)
	25		135.4	134.0	128.1	121.1	112.9	101.0	96.3	90.9	79.1	62.9	56.9	50.3	(72, 87, 154)
	50		211	204	193	184	173	155	148	139	122	96.3	86.5	76.0	(109)
$TlNO_3$	0		80.65	79.80	78.20	76.36	73.87	69.38	66.9	64.78					(114)
	18	125.57	124.67	123.44	121.07	118.34	114.60	107.90	104.80	101.14					(138, 185)
	25		144.24	142.56	139.50	136.37	132.04	124.25	120.7	116.60					(114)
	100									312	290	252	234	212	(208)
$\frac{1}{2}Zn(NO_3)_2$	0			61.8	60.6	59.8	57.9	54.5	52.8	51.2	47.9	42.9			(109)
	18									80.5	75.2	67.2	63.6	59.2	(95)
	25		117	115.1	112.7	110.8	115.9	98.9	95.7	92.1	85.4	77.9			(109)
	50		191	185	177	171	163	152	148	143	131	112			(109)
$\frac{1}{2}Cd(NO_3)_2$	18		108.2	105.0	100.2	96.2	91.9	85.5	82.7	79.7	73.5	63.4	59.1	53.9	(85, 273)
	25				114.8	110.8	106.5	99.3	96.3	92.9	85.1	72.3	67.0	60.9	(85, 273)
$\frac{1}{2}Hg_2(NO_3)_2$															(193, 243, 262)
$\frac{1}{2}Cu(NO_3)_2$	0			64.9	63.1	61.0	58.5	54.8	53.4	51.7	48.2	42.9	40.6	37.6	(109, 245)
	18									81.9	76.0	67.2	63.0	57.8	(95)
	25		121.8	120.3	117.4	113.5	108.2	100.5	97.5	94.0	86.9	76.3	71.9	66.8	(72, 109)
$AgNO_3$	0	72.4	71.9	71.2	70.0	68.8	66.9	63.3	61.5	59.7	55.8	50.3	47.6	44.4	(60, 116, 185, 245)
	18	113.72	113.00	111.92	109.88	107.62	104.90	99.63	97.17	94.20	87.88	77.39	72.9	67.51	(99, 133, 191)
	25		130.1	128.7	126.6	124.1	120.9	115.0	112.1	108.7	101.8				(87, 153, 235)
	50			187	183	178	173	163	158.9	154.0	143.0	124.9			(109)
	100			353	334.0*	334.0	325.0	307.1	293.6†	288.6	260	228	212	194	(191, 208)
	156			539		507	486.8	(461.3 at $C = 40$) (431.4 at $C = 80$)							(191)
	217.8			727		673	639	(599 at $C = 40$) (552 at $C = 80$)							(191)
	280.9			877		790	(680 at $C = 40$)			(614 at $C = 80$)					(191)
	305.7			935		818	(680 at $C = 40$)			(604 at $C = 80$)					(191)
$\frac{1}{2}Mn(NO_3)_2$	18											66.8	63.2	58.9	(99)
$\frac{1}{3}Fe(NO_3)_3$	18											75.9	70.2	63.8	(99)
$\frac{1}{2}Co(NO_3)_2$	0			(62)	59.2	56.9	54.3	50.9	49.6	48.0	44.8	40.0	38.1	35.7	(109, 110)
	18											66.2	62.3	58.0	(99)
	25		116.5	113.9	109.9	106.3	101.6	94.9	92.1	89.2	83.0	73.6	69.9	65.5	(72, 109)
	50				176	169	162	150.5	146	141	131	115			(109)
$\frac{1}{2}Ni(NO_3)_2$	0			(60.0)	57.4	55.5	53.5	50.3	49.2	47.9	45.1	40.3	38.2	35.7	(109, 110)
	18											66.9	62.6	57.6	(99)
	50			183	177	171	163	151	147	141.5	130	113	106	97	(109)
$\frac{1}{3}Cr(NO_3)_3$	0			73.7	68.6	64.5	(60.4)	(54.5)	52.3	50.1	45.6	39.4	37.0	34.3	(109)
	18			130.7	117.6	108.6	99.4	88.6	(85.0)	80.2	74.0	64.8	61.0	55.9	(15, 99)
	19.8			134.5	120.7	110.9	101.7	90.6	(86.8)						(15)
	25			149.8	134.3	(123)	(112)	98.9	94.9	91.1	84.4	75.2	70.4	63.8	(109)
	50			258	229	(209)	(189)	164	156	148	133	112.6	104.1	94.5	(109)

* At $C = 12.5$.
† At $C = 80$.

TABLE 2.—(*Continued*)

	°C	$C = 0.5$	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$UO_2(NO_3)_2$	0	(*Also* at t = 12.5, 25, 35, 50, 65°C)													(109)
	25														(62, 164)
$\frac{1}{3}Al(NO_3)_3$	0		64	62.6	60.3	58.2	55.7	51.5	49.9	48.2	44.6	39.2	37.0		(109)
	25		125	120.4	114.0	108.5	102.9	94.8	91.5	87.9	80.5	69.6	65.0		(109)
	50		224	211	194	181	168	151	145	138	126	107	100		(109)
$\frac{1}{3}La(NO_3)_3$	0			68.9	(65.3)	62.4	(59.0)	54.0	52.0	49.9	46.0				(186)
	18			110.7	(104.8)	100.0	(94.5)	86.6	83.6	80.2	(73.6)	64.0	59.7	54.0	(99, 186)
	25		133.5	128.8	(122.2)	116.4	(109.6)	99.6	95.8	91.7	83.4				(177, 186)
$\frac{1}{2}Be(NO_3)_2$	18											63.8	60.2	56.2	(99)
$\frac{1}{2}Mg(NO_3)_2$	0		(64)	63.1	61.1	59.5	57.6	54.2	52.9	51.4	48.1	42.7	40.5	37.9	(109, 110)
	18		102.5	100.7	97.6	94.52	90.8	85.2	82.9	80.4	75.2	67.2	63.9	59.5	(48, 105, 185)
	25		119.4	117.3	113.6	109.90	105.6	98.9	97.3	94.0	87.1	70.7	72.3	67.2	(105, 135, 185)
	50				179	173	165	154	149	144	134	117	110	103	(109)
$\frac{1}{2}Ca(NO_3)_2$	0			66.4	64.1	62.2	59.8	55.5	53.1	51.8	47.8	41.6	39.4	36.2	(109, 110, 186)
	18	109.78	108.34	106.39	103.93	99.39	95.05	88.29	85.38	82.37	75.84	65.61	61.22	55.79	(133, 135)
	25			123.6	119.5	115.8	110.9	102.5	99.3	95.7	88.4	77.0	72.5	66.7	(135, 186)
	50				183	177	168	155	150	143	130	113			(109)
$\frac{1}{2}Sr(NO_3)_2$	0	66.9	66.0	64.7	62.4	60.2	57.4	53.8	51.1	49.1	44.8	37.9	35.2	32.2	(109, 116)
	18	109.61	108.16	106.20	102.60	98.90	94.39	87.18	84.17	80.82	73.70	62.64	58.00	52.00	(133, 185)
	25			124	119.5	115.3	109.8	101.0	97.7	93.8	85.4	72.2	66.5	59.8	(109, 135)
	50				184	177	168	155	149	143	129	110			(109)
$\frac{1}{2}Ba(NO_3)_2$	0	71.2	70.0	68.4	66.2	63.6	59.8	54.1	51.5	48.7	42.6				(109, 116, 135, 185)
$Ba(NO_3)_2$	0*		137.60	133.57	126.34	119.29	110.67	97.18		85.47	72.08				(211)
$\frac{1}{2}Ba(NO_3)_2$	18	113.14	111.56	109.35	105.14	100.82	95.53	86.69	81.5	78.83	70.08	56.52			(133, 185, 191)
	25			124.4	120.2	115.8	110.3	100.6	96.3	91.6	81.7	65.8	59.5		(87, 109, 135)
	50				188.8	179.5	169.4	153.9	147.9	140.9	125.5				(109, 140)
	100	(315.5 at C = 12.5)		351.5		321.5		273.1		248.6	(279.6 at C = 40) (257.1 at C = 60)				(191)
	156			536		481	(412 at C = 40) (372 at C = 80)								(191)
	217.8			714		618	(507 at C = 40) (449 at C = 80)								(191)
	280.9			827		657	(503 at C = 40) (430 at C = 80)								(191)
	305.7			823		615	(448 at C = 40)								(191)
$LiNO_3$	0		54.9	54.8	54.6	53.6	51.5	49.4	48.6	47.4	44.7	41.0			(109)
	18	93.23	92.58	91.68	90.05	88.33	86.15	82.46	80.85	78.95	74.79	67.80		60.61	(137, 185)
	25		103	102.7	100.6	98.5	95.7	91.0	89.0	86.5	81.7	75.2			(109)
	50			162	157.4	150.8	143.6	141.5	138.8	130.7					(109)
$NaNO_3$	0		(64.7)		63.4	62.6	60.8	57.7	55.8	54.5	51.4	46.3	43.8	41.9	(109, 185, 245)
	18	103.38	102.60	101.65	99.83	97.93	95.43	91.22	89.42	87.04	82.09	73.88	70.07	65.72	(48, 137, 185)
	25		120.4	119.1	116.3	113.7	110.7	105.8	102.5	98.7	92.0	83.0			(109, 195)
	50		185.0	182.3	178.2	174.1	169.3	161.6	157.9	153.4	143.3	128.0			(109, 238)
	100		331.5	326.5	320.5	312.5	302.6								(263)
KNO_3	0	79.29	78.89	78.25	77.09	75.60	73.70	70.29	68.8	66.80	63.4	57.4			(109, 186, 263)
	18	124.16	123.37	122.32	120.21	117.93	114.96	109.62		104.56	98.53	89.12	85.08	80.33	(137, 185, 263)
	25			140.5	138.3	135.7	132.3	126.10	123.3	120.16	113.26	101.4			(26, 87, 109, 186)
	50			212.4	208.9	204.6	199.0	189.4	185.2	180.1	169.0	151.0			(109, 186)
	100	377.7	374.7	370.6	363.3	354.8	344.1	326.7	318.7	309.3					(186, 263)
	128			461.8	(436.7 at C = 12.5)			404.8		381.9					(186)
	156			551.9	(522.4 at C = 12.5)			479.4		451.3					(186)
$RbNO_3$	6											72.7	69.3	65.6	(49)
	18									112.6	105.7	95.3	90.8	85.6	(95)
	30											118.7	112.7	106.0	(49)
$CsNO_3$	0	83.0	82.4	81.7	80.2	78.5	76.4	72.7	71.0	69.3	65.3	59.0			(263, 265)
	18	128.4	127.4	126.2	123.6	121.1	117.9	(112.0)	(109.4)	106.4	100.1	90.7	86.7	82	(99, 263)
	100	382.5	379.0	375.0	367.0	358.6	347.0								(263)

* Concentrations are m(= millimole/kg H_2O) and the conductance data $10^6\kappa/m$.

TABLE 3.—(*Continued from p. 231*)

Cl.—(*Cont'd*)

½MgCl₂.—(*Cont'd*)

C	$10^6\kappa/C$
25°	
2 000	60.4
3 000	49.2
4 000	39.6
5 000	31.1
7 984	15.79
9 363	9.95

½CaCl₂

See also p. 240

C	$10^6\kappa/C$
0°	
2 000	37.89
3 000	32.94
4 000	28.21
5 000	23.48
6 000	19.14
7 000	15.36
8 500	(9.94)
18°	
2 000	58.02
3 000	49.7
4 000	42.4
5 000	35.6
7 000	23.5
8 468	16.13
25°	
2 000	66.65
3 000	56.6
4 000	48.35
5 000	40.7
6 000	33.40
6 915	27.60
8 418	18.89
50°	
4 910	61.1
6 879	42.0
100°	
2 000	167
3 000	140
4 000	119
5 000	101
6 000	85.5
7 000	71.6
7 911	56.9
9 070	46.8

½SrCl₂

C	$10^6\kappa/C$
0°	
2 000	(41.0)
18°	
2 000	57.5
3 000	49.7
40°	
1 369	94.9
100°	
2 000	164
3 000	138
4 000	118
5 000	99

½BaCl₂

C	$10^6\kappa/C$
0°	
2 000	40.6
3 000	35.3
18°	
2 000	60.50
3 000	51.5
25°	
2 000	68.5
3 000	58.2
100°	
1 400	182.6
2 000	164.4
3 000	141.6

LiCl

C	$10^6\kappa/C$
0°	
2 000	33.67
3 000	28.81
4 000	24.74
5 000	21.11
6 000	17.77
7 000	14.55
8 000	12.04
9 000	9.65
10 000	7.42
11 000	5.42
12 000	3.03
18°	
2 000	53.0
3 000	45.2
5 000	33.3
10 000	11.3
25°	
2 000	61.7
3 000	52.9
4 000	44.7
5 000	37.8
6 000	31.7
7 000	26.0
8 000	20.9
9 000	16.4
10 000	13.2
11 000	10.4
12 000	8.14
14 040	5.11
50°	
2 000	95.6
5 000	57.5
7 000	39.3
10 000	21.6
100°	
2 000	164
3 000	137.1
4 000	116.4
5 000	98.8
6 000	83.7
7 000	71.7
8 000	60.8
9 000	50.8
10 000	41.1

NaCl

C	$10^6\kappa/C$
0°	
2 000	41.4
3 000	36.5
4 000	31.5
5 000	26.6
5 500	24.6
18°	
2 000	64.66
3 000	56.4
4 000	42.6
25°	
5 000	44.7
100°	
2 000	209.7
3 000	184.1
4 000	164.6

KCl

C	$10^6\kappa/C$
0°	
2 000	63.5
3 000	62.2
18°	
2 000	92.3
3 000	88.1

RbCl

C	$10^6\kappa/C$
6°	
2 000	77.1
3 000	75.4
4 000	73.9
18°	
2 000	97
3 000	93
4 000	88

CsCl

C	$10^6\kappa/C$
0°	
2 000	67.0
3 000	65.9
4 000	63.5
5 000	59.2
6 000	53.7
7 000	(47.2)
18°	
2 000	94.2
3 000	88.7
4 000	(85.7)
50°	
2 000	144.6
3 000	135.1
4 000	125.8
5 000	103.2
6 000	99.9
7 000	86.5
8 000	(72)
100°	
5 000	(164)
6 000	141.0
7 000	121
8 000	102
8 500	93.1
9 000	(84)

Br

NH₄Br, 18°

C	$10^6\kappa/C$
2 000	97.6
3 000	93.7
4 000	90.0

⅓InBr₃, 18°

C	$10^6\kappa/C$
2 000	19.83
3 000	14.42
4 000	10.10

½ZnBr₂, 25°

C	$10^6\kappa/C$
2 000	54.9
3 000	40.0
4 000	29.9
5 000	22.7
6 000	17.7
7 000	14.5
8 000	10.75
10 300	6.71
13 700	2.95
16 400	1.36
19 700	0.487

½CdBr₂

C	$10^6\kappa/C$
18°	
2 000	12.8
3 000	9.35
4 000	6.00
5 000	(5.1)
25°	
2 000	15.01
3 000	10.64
4 000	8.40
5 000	(6.16)
50°	
2 000	21.7
3 000	16.6
4 000	12.8
5 000	10.18
6 000	7.90
7 000	6.18
8 000	4.38
9 000	2.90

½MnBr₂, 18°

C	$10^6\kappa/C$
2 000	53.54
3 000	43.6
4 000	35.64

½FeBr₂, 18°

C	$10^6\kappa/C$
2 000	51.9
3 000	41.94
4 000	33.65
5 000	26.25

½CoBr₂, 18°

C	$10^6\kappa/C$
2 000	54.7
3 000	45.5
4 000	37.56

½NiBr₂, 18°

C	$10^6\kappa/C$
2 000	54.5
3 000	45.1
4 000	37.40

⅓CrBr₃, Violet, 18°

C	$10^6\kappa/C$
2 000	51.3
3 000	41.3
4 000	33.22

½MgBr₂, 18°

C	$10^6\kappa/C$
2 000	54.1
3 000	45.2
4 000	38.1

½CaBr₂, 18°

C	$10^6\kappa/C$
2 000	62.0
3 000	53.0
4 000	45.7

½SrBr₂, 18°

C	$10^6\kappa/C$
2 000	62.0
3 000	53.5
4 000	45.6

½BaBr₂, 18°

C	$10^6\kappa/C$
2 000	64.7
3 000	56.0
4 000	48.3

LiBr, 18°

C	$10^6\kappa/C$
2 000	57.7
3 000	50.5
4 000	44.2

NaBr, 18°

C	$10^6\kappa/C$
2 000	69.1
3 000	60.5
4 000	53.0

KBr

C	$10^6\kappa/C$
0°	
2 000	67.7
3 000	66.3
18°	
2 000	96.5
3 000	91.9
4 000	86.9
50°	
2 000	157.1
3 000	145.6
4 000	132.2

RbBr

C	$10^6\kappa/C$
6°	
2 000	(78.3)
3 000	(76.0)
4 000	74.0
18°	
2 000	0.9264*
4 000	0.8227*

* A_C/A_{500}.

CsBr, 18°

C	$10^6\kappa/C$
2 000	(95.5)
3 000	89.8
4 000	84.1

I

NH₄I, 18°

C	$10^6\kappa/C$
2 000	99.9
3 000	95.5
4 000	91.3

½ZnI₂, 25°

C	$10^6\kappa/C$
2 000	62.4
3 000	44.8
4 000	30.4
5 000	20.7
6 000	14.8
7 000	10.6
9 250	4.90
10 800	2.90
13 900	0.916

½CdI₂

C	$10^6\kappa/C$
18°	
2 000	12.13
3 000	9.83
4 000	7.95
25°	
2 000	14.03
3 000	11.38
4 000	9.18
100°	
1 914	33.3

½MgI₂, 18°

C	$10^6\kappa/C$
2 000	58.6
3 000	49.4
4 000	41.0

½CaI₂, 18°

C	$10^6\kappa/C$
2 000	66.1
3 000	57.3
4 000	49.1

½SrI₂, 18°

C	$10^6\kappa/C$
2 000	66.0
3 000	56.8
4 000	47.8

½BaI₂, 18°

C	$10^6\kappa/C$
2 000	68.4

LiI, 18°

C	$10^6\kappa/C$
2 000	60.6
3 000	52.7
4 000	46.2

NaI

C	$10^6\kappa/C$
18°	
2 000	70.1
3 000	61.8
4 000	53.9
25°	
2 000	82.9
3 000	73.4
4 000	63.8
5 000	53.8
6 000	44.8
7 000	36.0

KI

C	$10^6\kappa/C$
0°	
2 000	70.1
3 000	68.8
4 000	66.4
5 000	62.9
18°	
2 000	99.6
3 000	92.8
4 000	89.4
5 000	80.6

I.—(*Cont'd*)

RbI

C	$10^6\kappa/C$
6°	
2 000	81.9
3 000	79.2
4 000	74.6
18°	
2 000	101.6
3 000	96.8
4 000	89.9
30°	
2 000	121.9
3 000	114.2
4 000	105.2

SO_4

$\frac{1}{2}(NH_4)_2SO_4$

18°	
2 000	60.3
3 000	54.6
4 000	49.5
5 000	44.6
6 000	(39.5)
25°	
2 000	67.8
3 000	61.7

$\frac{1}{2}ZnSO_4$

18°	
2 000	20.0
3 000	15.60
4 000	11.95
5 000	8.90
25°	
2 000	23.20
3 000	18.20
4 000	14.18
5 000	10.68

$\frac{1}{2}CdSO_4$

18°	
2 000	17.92
3 000	13.98
4 000	10.82
5 000	8.28
25°	
2 000	20.5
3 000	16.1
4 000	12.8
5 000	10.0

$\frac{1}{2}CuSO_4$

18°	
2 000	19.99
2 500	17.90
3 000	(16.2)
25°	
2 000	23.2
2 500	20.9

$\frac{1}{2}MnSO_4$

18°	
2 000	18.53
3 000	14.17
4 000	10.76
5 000	8.05
6 000	5.80
7 000	(3.80)

$\frac{1}{2}MnSO_4$.—(*Cont'd*)

C	$10^6\kappa/C$
25°	
2 000	21.75
3 000	16.80
4 000	12.80
5 000	9.55
6 000	7.00
7 000	(4.85)

$\frac{1}{2}FeSO_4$

18°	
2 000	19.5
3 000	15.30
4 000	11.93
25°	
2 000	22.6
3 000	17.9
4 000	(13.9)

$\frac{1}{2}NiSO_4$

18°	
2 000	19.25
3 000	15.07
25°	
2 000	22.72
3 000	17.83

$\frac{1}{2}MgSO_4$

18°	
2 000	21.4
3 000	16.1
4 000	12.0
5 000	8.8
25°	
2 000	25.25
3 000	18.95
4 000	14.20
5 000	10.40

$\frac{1}{2}Li_2SO_4$, 18°

2 000	30.39
3 000	23.16
4 000	17.97
5 000	13.79

$\frac{1}{2}Na_2SO_4$, 18°

2 000	39.6

$\frac{1}{2}Rb_2SO_4$

6°	
2 000	54.3
3 000	49.4
18°	
2 000	69.9
3 000	63.2
30°	
2 000	85.8
3 000	77.0

NO_3

NH_4NO_3

0°	
2 000	55.3
3 000	52.0
4 000	48.3
5 000	44.7
6 000	(41.6)
7 000	(39.2)
8 000	(35.6)
8 418	31.0

NH_4NO_3.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	80.5
3 000	74.2
4 000	68.4
5 000	62.3
6 000	56.5
7 000	50.7
7 500	48.3
100°	
2 000	210
3 000	183
4 000	162
5 000	142
6 000	124
7 000	112
8 000	99.1
9 000	86.3
9 500	79.9
11 600	58.0
13 800	38.8
15 000	29.0

$\frac{1}{2}Pb(NO_3)_2$

18°	
2 000	30.68
2 500	27.05
25°	
2 000	36.5
2 500	31.6

$TlNO_3$, 100°

2 000	164
3 000	135
4 000	115
5 000	99
6 000	86.0

$\frac{1}{2}Zn(NO_3)_2$, 18°

2 000	47.9
3 000	38.85
4 000	31.08

$\frac{1}{2}Cd(NO_3)_2$

18°	
2 000	40.8
3 000	31.4
4 000	24.2
5 000	18.4
6 000	13.7
6 500	11.5
25°	
2 000	46.0
3 000	35.4
4 000	27.21
5 000	20.50
6 000	14.08
6 490	13.33

$\frac{1}{2}Cu(NO_3)_2$

0°	
2 000	29.7
3 000	23.4
4 000	18.3
5 000	13.98
6 000	10.49
7 000	7.70
8 000	(4.8)

$\frac{1}{2}Cu(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	45.5
3 000	36.3
4 000	28.4
9 872	4.69

$AgNO_3$

0°	
2 000	36.5
3 000	31.4
4 000	27.7
5 000	(24.6)
18°	
2 000	55.9
3 000	48.4
4 000	42.3
25°	
1 500	69.9
2 000	64.0
3 000	55.2
4 000	48.5
5 000	43.0
8 460	29.5
100°	
2 000	156
3 000	132
4 000	115
5 000	102
6 000	92
7 300	80.7
9 580	64.2
12 100	51.0
15 100	36.1

$\frac{1}{2}Mn(NO_3)_2$, 18°

2 000	47.5
3 000	37.9
4 000	30.30
5 000	23.54
6 000	17.66
10 000	4.66

$\frac{1}{3}Fe(NO_3)_3$, 18°

2 000	48.53
3 000	37.50
4 000	28.50

$\frac{1}{2}Co(NO_3)_2$

0°	
2 000	28.8
3 000	22.7
4 000	17.8

$\frac{1}{2}Co(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	46.8
3 000	37.6
4 000	29.9
5 000	23.30

$\frac{1}{2}Ni(NO_3)_2$

0°	
2 000	28.8
3 000	22.8
4 000	17.3
18°	
2 000	46.0
3 000	37.2
4 000	29.3
5 000	22.7
6 000	16.0

$\frac{1}{3}Cr(NO_3)_3$, 18°

2 000	43.25
3 000	33.34
4 000	25.54
5 000	18.97

$\frac{1}{3}La(NO_3)_3$, 18°

2 000	39.1
3 000	28.45
4 000	19.92

$\frac{1}{2}Be(NO_3)_2$, 18°

2 000	45.80
3 000	37.8
4 000	31.00
5 000	24.85

$\frac{1}{2}Mg(NO_3)_2$

0°	
2 000	31.5
3 000	26.8
18°	
2 000	47.9
3 000	39.2
4 000	32.1
25°	
2 000	54.7
2 500	49.7

$\frac{1}{2}Ca(NO_3)_2$

0°	
2 000	27.8
3 000	21.3

$\frac{1}{2}Ca(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	42.7
3 000	33.5
4 000	26.5
6 190	14.15
9 202	5.10
25°	
2 000	50.5
3 000	38.8
4 000	30.0
6 130	16.31
9 110	6.29

$\frac{1}{2}Sr(NO_3)_2$

18°	
2 000	38.4
3 000	28.9
4 000	21.1
5 000	16.4
25°	
2 000	44.5
3 000	33.70
4 000	25.60
4 470	22.56

$NaNO_3$

0°	
2 000	(35.1)
18°	
2 000	54.60
3 000	46.10
4 000	39.23

KNO_3, 18°

2 000	69.00
2 500	65.00
3 000	(61.3)

$RbNO_3$

6°	
2 000	57.1
18°	
2 000	73.7
2 500	68.9
3 000	(64.4)
30°	
2 000	90.5
2 500	84.5
3 000	(79.2)

Specific conductance of $CaCl_2$ solutions (54)

Wt. %, $CaCl_2$	10°C	15°C	17.9°C	20°C	25°C	30°C
29.60	0.1377	0.1554	0.1656	0.1730	0.1910	0.2095
37.30	0.0975	0.1114	0.1197	0.1260	0.1412	0.1575
38.36	0.0906	0.1039	0.1120	0.1180	0.1324	0.1474
40.73	0.0742	0.0858	0.0930	0.0985	0.1120	0.1259
41.98	0.0678	0.0797	0.0865	0.0918	0.1043	0.1177
45.95	0.0426	0.0520	0.0573	0.0612	0.0711	0.0817

PART II. CONDUCTIVITY OF STRONG ELECTROLYTES*

HENRY C. PARKER AND ALFONS KLEMENC†

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TABLE 1.—VALUES OF C UP TO 0.5

For Literature References, *v.* Table 2

𝔅-Table.—Standard arrangement; *v.* Vol. III, p. viii

HCl, 25°

C	Λ
0.05	424.84
0.1	424.64
0.2	424.24
0.3	423.84

HIO_3, 25°

0.01	388.96
0.02	388.90
0.03	388.85
0.05	388.74
0.1	388.47
0.2	387.93
0.3	387.40

$\frac{1}{2}H_2SO_4$

t, °C	Λ
C = 0.2	
18	374.4
25	417.9
50	566.1
75	692.6
100	779
128	806
156	758

HNO_3

C = 0.3	
18	373.7

H_3PO_4

C = 0.2	
18	330.4
25	366.8
50	492.4
75	599.6
100	687.7
128	761.2
156	803.7

$TlH(C_4H_4O_6)$

C = 0.2	
18	373

$\frac{1}{2}MgC_2O_4$, 18°

C	Λ
0.1	94.4
0.2	86.9

$\frac{1}{2}Ca(HCO_3)_2$, 25°

C	Λ
0.1	(109.5)
0.2	(106.0)
0.3	104.2

$\frac{1}{2}Ca(C_2H_3O_2)_2$, 18°

0.1	82.2

$\frac{1}{4}Ca_2Fe(CN)_6$, 0°

0.2	67.5
0.3	64.4

$\frac{1}{2}Sr(C_2H_3O_2)_2$, 18°

0.1	82.4
0.2	82.0

$\frac{1}{4}Sr_2Fe(CN)_6$, 0°

0.2	66.8

$LiIO_3$, 18°

0.1	66.57
0.2	66.34

$LiClO_4$

0°	
0.2	54.3
18°	
0.2	87.9
100°	
0.2	293.1

$NaClO_3$, 18°

0.1	97.4
0.2	97.0

$NaBrO_3$, 18°

0.1	90.8
0.2	90.5

$NaIO_3$, 18°

0.1	76.58
0.2	76.33

$NaHCO_3$, 25°

0.1	(97.4)
0.2	(96.0)
0.3	95.2

$NaC_2H_3O_2$, 18°

0.1	77
0.2	76.5

$Na_4C_{11}H_2O_{10}$, Benzenepentacarboxylate

C	Λ
0°	
0.2	245
25°	
0.2	483
50°	
0.2	774

$Na_5C_{11}HO_{10}$, Benzenepentacarboxylate

0°	
0.2	325
25°	
0.2	640
50°	
0.2	1019

$NaC_4H_6BrO_2$, α-Bromobutyrate

0°	
0.24	46.1
15°	
0.24	70.6
25°	
0.24	89.7
35°	
0.24	110.1

$KClO_3$, 18°

0.1	118.45
0.2	118.17

$KClO_4$, 100°

0.2	371.5

KIO_3

18°	
0.1	97.50
0.2	97.20
25°	
0.2	112.84

$\frac{1}{2}K_2C_2O_4$, 18°

0.1	124.90
0.2	124.64

$\frac{1}{2}KHC_2O_4$, 18°

C	Λ
0.2	274.0
0.3	247.3

$KC_2H_3O_2$, 18°

0.1	100
0.2	99

$\frac{1}{2}K_2C_8H_4O_4$, Phthalate, 25°

C	Λ
0.4	(123.3)

$KHC_8H_4O_4$, Biphthalate, 25°

0.1	152.7
0.2	141.8

$KC_6H_2N_3O_7$, Picrate, 0°

C	Λ
0.2	54.9
18°	
0.2	88.7

KCNS, 18°

0.1	119.94
0.2	119.74

TABLE 2; *see* p. 242 to 253

TABLE 3.—VALUES OF C ABOVE 1000

For Literature References, *v.* Table 2

𝔅-Table.—Standard arrangement; *v.* Vol. III, p. viii

HCl

C	$10^6\kappa/C$
18°	
2 000	253.8
3 000	214.7
4 000	(182)
5 000	152.0
10 000	64.3
25°	
2 000	282.4
35°	
2 000	316.6

$HClO_3$, 18°

2 000	246.7
3 000	205.0

$HClO_4$

25°	
2 000	291.5
3 000	226.0
4 000	185.7
5 000	150.0
6 000	118.4
7 000	91.0
8 000	68.4
9 000	52.0
10 000	41.4
11 000	31.7
12 000	23.1
13 000	16.4
50°	
4 250	232
13 300	22.8

HBr, 18°

2 000	253.3
3 000	213.1
4 000	176.4
5 000	145.9

HI, 18°

C	$10^6\kappa/C$
2 000	254.4
3 000	(212.8)
4 000	178.4
5 000	146.7

HIO_3, 18°

2 000	106.0
3 000	(85.0)
4 000	70.4

$\frac{1}{2}H_2SO_3$

0°	
1 012	27.9
1 936	20.4
20°	
1 012	33.4
1 936	24.5
25°	
1 012	34.1
1 936	24.9

$\frac{1}{2}H_2SO_4$, 18°

2 000	182.7
3 000	166.5
4 000	150.5
5 000	134.6
6 000	119.1
7 000	105.0
8 000	92.3
9 000	80.8
10 000	70.3
11 000	(60.6)
16 248	28.12
23 047	9.35
27 180	4.54
29 840	3.32
30 900	3.17
31 410	3.145
31 900	3.165

$\frac{1}{2}H_2SO_4$.—(*Cont'd*)

C	$10^6\kappa/C$
32 390	3.188
33 340	3.219
33 800	3.232
34 260	3.215
34 710	3.155
35 580	2.876

HNO_3

18°	
2 000	259.1
3 000	220.0
4 000	184.4
5 000	154.6
6 000	129.1
7 000	108.6
8 000	91.9
9 000	77.6
10 000	64.9
16 500	20.43
17 000	17.65
18 000	12.55
19 000	8.50
20 000	5.50
21 000	2.90
22 385	1.009
22 870	0.6690
23 660	0.8538
23 800	1.667
24 060	1.720
25°	
2 000	289.8
3 000	242.2

$\frac{1}{3}H_3PO_4$, 0°

2 000	24
6 000	14.3
7 000	13
8 000	11.7
11 000	11.3
12 000	11

Continued on p. 254

* Except halides, nitrates and sulfates, for which *see* p. 230, and soap solutions, for which *see* Vol. V, p. 458.

† Critical compilation by Henry C. Parker. Graphical interpolation to round values of C by Alfons Klemenc.

TABLE 2.—VALUES OF Λ BETWEEN C = 0.5 AND 1000,* STANDARD ARRANGEMENT; *v.* Vol. III, p. viii

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
HCl	0		261.4	260.6	259.15	257.2	254.43	249.87	247.80	245.30					(212); *cf.* (14, 109)
	12.5														(109)
	18		377	375.5	372.4	369.3	364.9	357.6	354.1	350.1	341.5	326.6	316.6	300.5	(79, 128, 135, 157, 183); *cf.* (31)
	19.8														(224)
	20														(103.5, 145)
	25				415.6	412.0	407.3	399.0		391.3	381.3	360.6		331.9	(163.5)
	25	423.04 (417.91 at C = 31)	421.38	419.17	415.11	411.08	406.07	397.80	393.9	389.8	379.6	359.2	348.5	332.8	(24, 145, 198); *cf.* (25, 71)
	35	(For 45°C, *v.* (140); for 51 and 81°C, *v.* (31))				476	470	460	455	450	436	408.6	392.2	374.8	(109, 135)
$HClO_3$	18								(347.6)	343.6	334.6	316.6	306.2	291.4	(93, 95); *cf.* (48)
	25	(For 50°, *v.* (150))			400	396	391	382	379	375	366	352			(195)
$HClO_4$	25				405	405	402	393.0	389.0	384.4	373.8	359.0	352.5	342.5	(150, 195, 246)
HBr	18									355.2	347.7	328.4	316.5	301.1	(95)
	25					418	410.7	400.2	396.0	391.2	380.7	362.2	351.0	334	(58, 196)
$HBrO_3$	25		400	395	386	377	366								(196)
HI	18									346.4	339.2	323.0	311.6	296.8	(93, 155)
	25		420.0	418.2	415.2	412.0	407.8	400.8	397.4	393.2	383.4	367			(195, 249, 266)
HIO_3	18		344.59							252.3	219.7	174.5	158.4	141.2	(95, 141)
	25	386.34	383.95	379.93	370.85	359.69	343.04	310.66	295.60	278.34	242.18	219.5	191.6		(83, 141, 195)
HIO_4	25		386	372	335	297	253	192	172	150	110				(195)
$\frac{1}{2}H_2SO_3$	0	(93.6 at C^* = 16.3)				(63.0 at $C\dagger$ = 107.3)									(151)
	20	(127.6 at C^* = 16.3)				(80.1 at $C\dagger$ = 107.3)									(151)
	25	(133.7 at C^* = 16.3)				(82.7 at $C\dagger$ = 107.3)									(151)
$\frac{1}{2}H_2SO_4$	0					226.1	211.1	191.2	183.9	176.9	165.2	155.3			(105, 109)
H_2SO_4	0‡		471.7	456.3	426.4	399.0	369.3	333.3		310.9					(211)
$\frac{1}{2}H_2SO_4$	18	371.3		353.4		308.6		253.1	243.5	232.9	(For 14, 26, 38°C, *v.* (173, 174))			198.6	(75, 105, 125, 127, 184)
	25	413.1	(399.5)	390.3	(364.9)	336.4	308.0	272.6	261.5	250.8	234.3	222.5	(For 35°C, *v.* (109))		(105, 109, 184)
	50	552.6	(528)	500.6	(448)	405.4	367.3	322.9	309.8	299.9					(184)
	75	656.1	(608)	560.0	(481)	434.4	395.7	355.5	345.0	335.9					(184)
	100	705		570	(488)	445	414	384	375	368					(184)
	128	695		550	(485)	(458)	438	416	410	403					(184)
	156	643		535	(498)	480	(463)	447	442	434					(184)
	218	585		562	(545)	532	521	501	492	482					(184)
	306			636					(473 at C = 80)						(184)
$\frac{1}{2}H_2S_2O_4$	18					258.4	237.6	199.6	184.6	168.0		(*Also* at 25°C)			(107)
$\frac{1}{2}H_2S_2O_6$	25			414	410	405	399	389	385	379	367				(195)
$\frac{1}{2}H_2S_4O_6$	25			421	414	408	400	388	383	378	367				(195)
$\frac{1}{2}H_2SeO_4$	25			384	366	349	328	295	283	272	253	233	226	219	(195)
$\frac{1}{6}H_6TeO_6$	25		17.9	6.3	2.9	1.85	1.30	0.73							(231)
HNO_3	0					253.4	251.7	248.6	247.1	245.3	241.3				(109)
	18	373.3	372.6	370.6	366.8	364.0	360.4	353.0	349.6	345.7	336	321.5	315.5	305.5	(79, 132, 135, 184, 255)
	25				411.2	407.3	402.4	394.0		386.0	376.1	356.5		329.8	(163.5)
	25	416.2	414.6	412.9	409.0	405.2	400.8	392.5	388.7	384.2	374.4	356.6	347.0	333.2	(109, 184, 246)
	35					455.8	450.4	441.4	437.4	432.6	419.0				(109)
	50	562.8	(560.7)	557.7	(552)	546.9	(540)	527.4	(521.9)	514.7					(184)
	75	695.7	(692.3)	688.3	(681.6)	674.7	665.2	647.6	639.6	630.6					(184)
	100	813.2	(809)	804.6	(795)	784.5	(772)	748.6	737.7	727.0					(184)
	128	928		917	(904)	891	(872)	843	(830)	815					(184)
	156	1026	(1018)	1010	(993)	976	(954)	915	(898)	878					(184)
	218			1164			(924 at C = 80)								(184)
	306			1154					482			(453 at C = 80)			(184)
NH_4NO_2	20			110	109	106	103	96							(215.5)
NH_4ClO_4	18										96.0	90.2		83.8	(99)
NH_4IO_3	0		60.6	60.2	58.7	57.0	55.0	52.1							(267)
	25		114	113	110	107	103	97		(*Also* at 35°C)					(267)

* When the literature cited contains data at other temperatures this is indicated thus: (*Also* at 25°C). † Values of C are for t = 0°C. (For 10, 30, 40, 50, 60, 70°C, *v.* (151).) ‡ Concentrations are m (= millimole/kg H_2O) and Λ values are $10^6\kappa/m$.

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
NH_4HSO_4	0		316	308	292	275	253	223	213	202.2		165.3			(109)
	25		514	492	454	416	372	(275 at C = 125)				226			(109)
$\frac{1}{3}H_3PO_4$	0		(For 17°C, *v.* (13))									31.7	30	28.3	(204); *cf.* (41)
H_3PO_4	18			282.8	(273.0)	202.7	(166.7)	122.5	(108.7)	96.4					(184)
	25			311.5		221.7	(180.3)	132.4	(117.7)	103.9					(184)
	50			400.2		272.7	(216)	157.6	(139.2)	122.5					(184)
	75			463.0		299.6	(236)	168.4	(148.4)	129.7					(184)
	100			463.0		307.6	(236)	167.6	(148.2)	128.2					(184)
	128			507.0		297.6	(226)	157.8	(138.0)	120.0					(184)
	156			488.4		273.6	(206)	141.8	(123)	107.6					(184)
$\frac{1}{4}H_4P_2O_6$	25				151.6	136.4	122.5	107.6	103.1	98.6					(254)
$H_4P_2O_6$	20		627	565	489	443.7	405.8								(254)
NH_4PO_3	18														(250)
$\frac{1}{3}NH_4H_2PO_4$	0				19.5	18.9	18.2	17.2	16.8	16.4	15.6	14.1			(267)
	25				35.7	34.5	33.7	32.4	31.7	30.9	29.1	26.1			(267)
	35				43	42	41.0	39.4	38.6	37.6	35.2	31.6			(267)
$(NH_4)_2HPO_4$	17														(13)
$(NH_4)_3PO_4$	17														(13)
H_3AsO_4	25		308.2	279.8	230.0	187.0	150.8	103.4	91.4	80.0					(261)
H_3SbO_4															(160.5)
$NH_4C_2H_3O_2$	18				92.9	91.4	89.0	84.9	82.7	(79.5)	(73.2)	(63.8)	(59.6)	54.7	(95, 187, 189)
	100					299.2		(286.0 at C = 25)							(189)
	156					455		(525 at C = 25)							(189)
	218		(217.4 at C = 5.97)				319.1								(189)
	306					81.4		(81.8 at C = 29.35)							(189)
$C_aH_bN_2O_2$	Various substituted ammonium nitrites														(215.5, 217)
$C_3H_5N_3O_4$	27.5			115.3	111.2	108.3	105.3	$CH(CN)NO_2COONH_4$							(253)
$C_3H_7N_3O_5$	27.5		115.2	113.3	109.7	105.9	101.4	$CONH_2.CHNO_2.COONH_4$							(253)
$C_3H_9N_3O_6$	27.5			109.2	104.7	101.1	97.4	$(NH_4O_2C)_2CHNO_2$							(253)
$C_8H_{14}N_2O_2$	25		77.2	76.3	74.2	(72.2)	Piperidine cyanoacetate								(175)
$C_{14}H_{22}N_4O_7$	0	30.4	30.0	29.6	28.9	28.1	26.9	Tetraethylammonium picrate							(263)
	18	51.9	51.3	50.6	49.3	47.8	45.8								(263)
	100		189.2	185.7	179.7	173.2	164.3								(263)
$C_{17}H_{19}N_3O_6$	25		56.6	55.2	52.9	50.6	(47.1)	Diethylphenylammonium 3-5-dinitrobenzoate							(149)
CH_5ClN	18	(114.8)	114.1	112.9	110.8			CH_3NH_2HCl				(*Also* at 32.35°C)			(172)
	25		133.1	131.8	129.4	126.8	123.2	117.1	114.2	110.8					(34, 172)
C_2H_8ClN	18		108.1	107.1	(106.4 at C = 3)			$(CH_3)_2NHHCl$							(172)
	25	(126.6)	125.7	124.4	122.0	119.6	116.4	110.6	107.9						(34, 172)
C_2H_8ClN	18	102.5	101.8	100.6								$C_2H_5NH_2HCl$			(172)
	25	120.9	120.1	119.0	(117.9 at C = 3)										(172)
$C_{17}H_{20}BrNO$	25				92.8	91.9	89.7	82.9	79.6	Allylbenzylmethylphenylammonium bromide					(268)
$C_{17}H_{22}BrNO$	25				92.8	91.9	89.7	82.9	79.6	Propylbenzylmethylphenylammonium bromide					(268)
$C_{22}H_{48}NI$	56	Triethylcetylammonium iodide													(220)
NH_4CNS	0		76.5	75.4	74.1	72.9	71.5	69.1	68.2	67.1	64.5				(267)
	18									104.1	99.5	93.8	91.7	89.7	(93, 95)
	25			137	134.8	132.7	128.8	123.9	121.6	119.0	114.0				(48, 267)
	35			164	161	158	154	148	145	142	136				(48, 267)
$C_6H_{13}N_2SI$	$[NH_2.CS.NHC_3H_5]C_2H_5I$														(77)
$\frac{1}{3}H_2SiF_6$	25		322	245	198	183	175	165	161	155	146	129	119	108	(195)
$\frac{1}{2}Pb(C_2H_3O_2)_2$	0		44.8	39.6	32.9	27.8	23.1	16.9	14.7	12.7	9.50	5.95			(109)
	18									21.4	15.95	10.15	8.37	6.67	(95)
	25		84	74.2	61.3	52.1	43.5	32.1	28.0	24.3	18.3	11.8	(*Also* at 50 and 65°C)		(109)
	35		101	89	74	62	52	38	34	29	22	14			(109)
$\frac{1}{2}Pb(C_6H_5CO_2)_2$	30														(61)
$Tl(OH)$	25			248	247	242	236	222	214	206	188				(195)
$TlClO_3$	20		123.9	(100.8 at C = 134.0)											(181)
	25		135.1	133.8	131.4	129.0	125.8								(72)
$TlClO_4$	25		143.4	141.6	138.8	136.2	132.5								(72)
$TlBrO_3$	25		127.8	126.6	124.3	(121.8)									(72)
$TlIO_3$	25		112	111.4											(72)
$\frac{1}{4}Tl_2S_2O_6$	25		170.3	166.3	157.2	148.2	138.2								(72)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$TlHSO_4$	18	493.0	477.5	(454.4)	413.0	376.0	337.4	289.6	275.5	262.0	(248.2 at C = 150)				(65)
$\frac{1}{2}Tl_2SeO_3$	25		130.4	123.2	111.9	102.2	90.9								(72)
$\frac{1}{2}Tl_2SeO_4$	25		141.9	138.4	132.7	126.2	117.4								(72)
$\frac{1}{3}Tl_3PO_4$	25		122.7	122	114.5										(72)
$\frac{1}{3}TlH_2PO_4$	25				35.7	34.9	33.8	32.1							(72)
$\frac{1}{3}TlH_2AsO_4$	25			(36.5)	35.6	34.9	33.9	32.1							(72)
$\frac{1}{3}Tl_2HAsO_4$	25			56.4	55.7	54.6	52.8	49.2							(72)
$\frac{1}{2}Tl_2CO_3$	25		143.0	136.9	126.2	115.0	102.4								(72)
$TlH(C_4H_4O_6)$	18	282	250.6		104.2	93.9	85.2								(65)
$\frac{1}{2}Zn(ClO_3)_2$	18									73.9	69.0	61.7	58.4	54.3	(93, 95); *cf.* (47)
$\frac{1}{2}Zn(BrO_3)_2$	18											51.3	47.6	43.2	(99)
$\frac{1}{2}Zn(NO_2)_2$	20														(215.5)
$\frac{1}{2}Zn(C_2H_3O_2)_2$	0		44.6	43.2	40.8	38.8	36.3	31.4	29.1	26.6	22.0	14.8			(109)
	25		90.7	86.1	79.2	73.7	67.6	57.4	53.0	48.5	39.2	25.3	19.1	11.8	(109, 236)
	35		106	103	97	91	83	70		59	46	19	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}Cd(ClO_3)_2$	18									75.0	69.9	62.1	58.6	54.3	(93, 95)
$\frac{1}{2}Hg(NO_2)_2$	20														(214)
$Hg_2NNO_2.\frac{1}{2}H_2O$															(216)
$\frac{1}{2}HgNCl_2H_2$	$\frac{1}{2}NH_2HgCl_2$														(215)
$HgCH_3OH$	25														(164)
$HgC_3H_6O_2$	25									4.9					(164)
$\frac{1}{4}Hg_2C_6Cl_4H_{12}$	$\frac{1}{4}(CH_2)_6.2HgCl_2$														(215)
$Hg_2C_8H_{16}S_2O_4$	18			67.7	57.0	48.7	40.6	30.2	(26.7)	$[Hg(SC_2H_5)_2.Hg](C_2H_3O_2)_2$					(247)
$HgC_aH_bN_c$, etc.	(For various complex salts of Hg with substituted NH_4 bases, *v.* (164, 214, 215, 216))														
$\frac{1}{2}Cu(ClO_3)_2$	18									75.7	70.6	62.7	59.2	54.7	(93, 95); *cf.* (47)
$\frac{1}{2}Cu(NO_2)_2$ and $Cu(NH_4)_2(SO_4)_2$															(123, 215.5)
$\frac{1}{2}Cu(C_2H_3O_2)_2$	18									22.9	17.3	10.9	8.70		(95, 99)
$AgClO_2$	25		111.0	109.1	105.4	102.0	(98.1)								(33)
$AgClO_3$	25		124.1	123.5	121.8	119.7	113.2								(153)
$AgClO_4$	25		128.0	127.1	124.7	122.6	119.8								(153)
$\frac{1}{2}Ag_2S_2O_6$	25		159.6	156.0	151.2	146.0	137.3								(153)
$AgHSO_4$	18	481	463	439.2	402.0	365.5	327.0	(290.0 at C = 42)							(65)
$AgNO_2$	25			128.3	115.6	112.3	85.4								(53); *cf.* (179)
$AgPO_3$	18														(250)
$AgC_2H_3O_2$	25		101.2	100.1	97.1	(99.0 at C = 3)									(153, 225); *cf.* (106)
$AgC_3H_7CO_2$	CH_3CH_2COOAg														(225)
$AgSO_3C_6H_5$	25		96.6	96.2	94.5	92.0									(153)
$AgSO_3C_9H_{11}$	25		89.0	87.6	85.6	83.0	79.6				Silver pseudocumenesulfonate				(153)
$AgSO_3C_{10}H_7$	25		101.3	99.8	97.6	95.5	(93.2)				Naphthalenesulfonate				(153)
$\frac{1}{2}Ag_2SiF_6$	25		117.5	116.4	113.8	110.8	107.4								(153)
$[Ir(NH_3)_5Br]Br_2$	95	753	727	695	641	596									(143)
$[PtNH_3(NH_2OH)_3]Cl_2$	18														(43)
$Pt_aN_bH_cX_dO_e$, etc.	(For various complex salts of Pt with NH_3 and $NH_aC_bH_c$, *v.* (43, 44, 45, 46, 61, 158))														
$\frac{1}{2}H_2Pt(CN)_4$	25			406	405	402	395	381							(261)
$HMnO_4$	25			402	400	395	389	378	374	369	358	336			(161)
$MnCl_2.Hg(CN)_2.2H_2O$	23		245	237		212	204		$MnHgC_2N_2Cl_2.2H_2O$						(86)
$AgMnO_4$	25		119.9	119.2	117.5	115.4	(111.9)								(72)
$FeNH_4O_8S_2$									$NH_4Fe(SO_4)_2.12H_2O$						(271)
$H_4Fe(CN)_6$	25	1360	1290	1210	1110	1040	970	890	850	790					(196)
$FeC_5N_8H_8O$	25		261	(253)	242.0	233.6	224.2	210.4	205.0	$(NH_4)_2Fe(CN)_5NO$					(40)
$FeC_6N_3H_{12}O_{12}$										$(NH_4)_3Fe(C_2O_4)_3$					(123)
$FeC_7N_8H_{12}O$	25		232.9	226.0	214.9	204.5	192.7			$(CH_3NH_3)_2Fe(CN)_5NO$					(40)
$FeC_8N_7H_{10}O$	25		207	201	189	178	164	142		$(CH_3)_3NHFe(CN)_5NO$					(40)
$FeC_9N_7H_{12}O$	25		219.7	213.0	202.1	192.2	180.5	161.5		$(C_2H_5)_2NH_2Fe(CN)_5NO$					(40)
$FeC_{13}N_8H_{12}O$	25		204.9	197.5	185.3	172.2	157.3	143.7	$[(CH_3)_4N]_2Fe(CN)_5NO$						(40)
$FeC_5NS_2H_6O_8$	Pyridine disulfatoferrate									$Fe(SO_4)_2HC_5H_5N.2H_2O$					(270.5)
$\frac{1}{3}Co(ClO_3)_2$	18											61.7	58.2	54.2	(99)
$CoN_6H_{20}O_4$	0		265.0	257.0	247.8	240.1	230.7			$Co(NH_3)_5H_2O(OH)_3$					(144)
$\frac{1}{3}Co(NH_3)_6(OH)_3$	0		154.2		142.0		132.1		(119.3)	115.5					(144)
	25		275		242		224			197					(144)
	(For other complex Co salts, *v.* (42, 61, 67, 88, 144, 158, 169, 242))														

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$CoN_6Br_3H_{18}$	0	90.6	(88.4)	85.7	(80.2)	(75.0)	69.9	63.9	60.0	56.7	$Co(NH_3)_6Br_3$				(88)
	25	171.0	(166)	160.1	(149)	(140)	130.2	118.1	111.3	103.5					(88)
$\frac{1}{3}CoN_6Br_3H_{18}$	0		90.1		83.0		71.7		(61.0)	58.0	$\frac{1}{3}Co(NH_3)_6Br_3$				(144)
	25		166.1		151.3		132.2		(112.2)	106.3					(144)
$\frac{1}{2}Co(C_2H_3O_2)_2$	0		44	42.9	41.1	39.3	37.1	32.5	30.5	28.1	23.5	16.9	14.4	11.8	(109)
	25		87 .1	84.5	79.9	75.3	70.0	61.1	57.4	53.4	45.1	32.8	(28.0)	22.6	(109, 236)
	35	(*Also* at 50 and 65°C)		102	98	93	86	74	69	64	54	39	33	27	(109)
$\frac{1}{2}Ni(ClO_3)_2$	18											61.9	58.4	54.2	(99)
$\frac{1}{2}Ni(NO_2)_2$	20														(215.5)
$Ni(C_2H_3O_2)_2$	0	87.6	84.8	81.7	76.7	71.6	64.6	53.6	49.2	44.5	35.0	21.4			(109)
	25	171.0	165.8	159.6	149.4	139.2	124.6	102.0	93.6	84.6	66.6	41.8			(109)
	35	209	203	196	183	168	151	124	114	102	80	51	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}NiH_2(COS)_4$	25		(3.83 at C = 1.38)		(3.67 at C = 2.76)										(223)
$Ni(NH_4)_2(COS)_4$															(223)
$\frac{1}{2}H_2CrO_4$	25					193	193	190	188	186					(261)
$CrCl_3H_{12}O_{18}$											$[Cr(H_2O)_6](ClO_4)_3$				(271)
$\frac{1}{2}Cr(NH_4)_2O_4$	0			76	76.0	73.8	70.6	65.0	62.7	60.8	55.9	49.8	(*Also* at 15°C)		(267)
	25			139	138.9	135.8	129.0	117.9	113.5	108.9	99.7				(267)
	35			166	163	160	153	141	136	130	118				(267)
Cr	(For complex chromium salts, *v.* (61, 123, 262, 270))														
$UO_2(C_2H_3O_2)_2.2H_2O$	0	81.7	74.4	67.5	58.8	52.5	46.0	38.5	36.2	34.0					(109)
	25	140	127.7	117.8	103.6	93.6	83.4	70.9	66.8	62.7					(109)
	35	164	150	137	122	111	100	87	82	78					(109)
$(VO)_2H_2(SO_4)_3$															(139)
$[Al(H_2O)_6](ClO_4)_3$															(271)
$\frac{1}{3}AlMo_6N_3H_{18}O_{24}$										$\frac{1}{3}(NH_4)_3H_6[Al(MoO_4)_6].7H_2O$					(229)
$\frac{1}{3}Y(C_7H_5O_3)_3.3.5H_2O$	20	79.8	74.8	(69.6 at C = 1.67)						Salicylate					(36)
$\frac{1}{3}Y(C_7H_5O_3)_3.6H_2O$	20	77.5	71.8	63.4	51.5	41.6				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}Y(C_7H_5O_3)_3$	20	70.1	63.6	55.2	43.1	33.6				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}La(IO_3)_3$	25	(99.0 at C = 3.09)													(90)
$\frac{1}{3}La(C_7H_5O_3)_3$	20	90.2	81.6	(75.1 at C = 1.67)						Salicylate					(36)
$\frac{1}{3}La(C_7H_5O_3)_3.6H_2O$	20	82	73.9	65.2	53.0	43.5				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}La(C_7H_5O_3)_3.2H_2O$	20	70.0	62.6	54.7	44.1	36.0				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.H_2O$	20	83.2	75.7	(69.7 at C = 1.66)						Salicylate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.6H_2O$	20	74.7	65.8	56.2	44.6	36.1				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.4H_2O$	20	77.0	58.6	49.7	38.2	30.6				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}Gd(C_7H_5O_3)_3.H_2O$	20	84.7	79.1	(71.0 at C = 1.6)						Salicylate					(36)
$\frac{1}{3}Gd(C_7H_5O_3)_3.6H_2O$	20	74.8	66.9	57.9	45.1	36.1				*m*-Hydroxybenzoate					(36)
$\frac{1}{2}Mg(ClO_3)_2$	18									76.1	70.6	62.7	59.2	54.8	(93, 95); *cf.* (47)
$\frac{1}{2}Mg(BrO_3)_2$	18											52.7	49.0	44.7	(99)
$\frac{1}{2}Mg(IO_3)_2$	25		92.3	89.2	84.4	80.1	75.2								(261)
$\frac{1}{2}MgS_2O_3$	25		134.8	128.6	119.3	111.0	101.3								(260)
$\frac{1}{2}MgSeO_4$	25		112.4	105.8	96.0	87.8	78.9								(260)
$\frac{1}{2}Mg(NO_2)_2$	20														(215.5)
$\frac{1}{2}MgC_2O_4$	18	74.4	63.3	51.3	38.1	29.6	23.0	16.4	14.5	12.7	10.0				(133)
$Mg(HCO_2)_2$	0		100	97	93.8	89.7	84.4	74.0	(69.8)	65.1	(54.4)	39.7			(109)
	18									110.4		66.14	(87.3 at C = 250)		(99)
	25				179	172	160	142		127	(*Also* at 35, 50, 65°C)				(109)
$\frac{1}{2}Mg(C_2H_3O_2)_2$	0		44.6	42.9	40.6	38.9	37.1	33.6	31.9	30.1	26.0	20.0			(109)
	18									51.3	44.6	34.2	29.8	24.9	(95, 222)
	25		87.2	84.4	80.4	76.9	72.7	65.4	62.1	58.8	50.4	38.6		29.0	(109, 222)
	35		108	106	101	96	90	80	76	72	62	(*Also* at 50 and 65°C)			(109)
$\frac{1}{2}MgPt(CN)_4$	25		158.1	152.1	142.9	135.2	126.2								(206)
$\frac{1}{4}Mg_2Fe(CN)_6$	25		153.5	139.8	123.0	112.4	102.7								(206)
$\frac{1}{2}MgCrO_4$	18									(56.5)	50.7	42.9	39.8	36.34	(95); *cf.* (47)
	25		118.7	113.6	104.2	95.9	86.8								(206)
$\frac{1}{2}Ca(OH)_2$	25				226	220	210								(195)
$\frac{1}{2}Ca(ClO_3)_2$	6											49.0	45.7	41.8	(48)
	18									79.9	75.0	68.0	64.8	60.6	(93, 95)
	18			(*Also* at 30°C)								65.5	61.0	55.8	(48)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}Ca(NO)_2$	0														(213)
$\frac{1}{2}Ca(NO_2)_2$	20														(215.5)
$Ca(HCO_2)_2$	0	108	106	104	101	96.6	91.2	82.0	78.0	73.5	64.9				(109)
	18	(89.7 at C = 250)										(73.7)	63.6	50.4	(99)
	25	203	199	195	189	183	172.5	153.5	146.0	137.2	119.6	(*Also* at 35, 50, and 65°C)			(109)
$\frac{1}{2}Ca(HCO_3)_2$	25	102.0	99.3	96.6	91.7	87.0	80.9								(120, 122)
$Ca(C_4H_4O_6).3H_2O$	30														(61)
$\frac{1}{2}Ca(C_2H_3O_2)_2$	18	80.6	79.5	77.7	75.0	71.8	67.6	60.2	57.2	54.0	47.0	36.0	31.4	26.4	(18, 95, 163); *cf.* (236)
$\frac{1}{2}Ca(C_2H_5CO_2)_2$	18										43.8	32.9	28.4	23.4	(99)
$\frac{1}{2}Ca(HCN_2)_2$	25					(114.7)	105.3	92.4	87.8	83.2	$Ca(CNNH_2)$				(117)
$\frac{1}{2}Ca(MnO_4)_2$	25		118.8	115.7	110.7	106.3	(101.5)								(72)
$\frac{1}{4}Ca_2Fe(CN)_6$	0	59.7	53.6	45.4	(37.3)	(31.9)	(27.6)	23.2	22.2	21.3	20.1	19.1	18.7	18.1	(12); *cf.* (186)
	18			75.4		49.8	(43.5)	38.4	36.7	35.0	32.8				(186)
	25	67.6	57.4	49.3	41.8	39.6	37.6	35.6	34.7	34.2	33.8				(239); *cf.* (186)
$\frac{1}{3}Ca_3(Fe(CN)_6)_2$	25	138.7	126.5	114.9	100.6	(90.8)	81.8	72.4	70.0	67.8	64.6	1.0	59.7	58.4	(239)
$\frac{1}{2}CaCrO_4$	0		60.9	59.3	55.6	(51.7)	46.7	39.9	37.7	35.6	31.9	6			(109)
	18		106.7	(101.4)	93.0	85.0	(76.2)	65.8	(62.3)	58.6	(52.0)	4.6	(42.0)	39.2	(133)
	25		113.8	110.8	103.0		85.6	73.5	69.3	65.3	58.5	4			(109)
	35		140	134	124	(114)	112	87.5	82.5	77.8	69.8	(*Also* at 50 and 65°C)			(109)
$\frac{1}{2}Sr(OH)_2$	25			225	224	220	214	204							(195)
$\frac{1}{2}Sr(ClO_3)_2$	18									79.2	73.8	65.4	61.9	57.8	(93, 95); *cf.* (47)
$\frac{1}{2}Sr(BrO_3)_2$	18										63.8	55.0	51.1	46.4	(99)
$\frac{1}{2}Sr(NO_2)_2$	20														(215.5)
$\frac{1}{2}Sr(HCO_2)_2$	18										60.6	49.8	45.7	41.0	(99)
$\frac{1}{2}Sr(C_2H_3O_2)_2$	0		51.8	49.6	46.6	44.6	42.5	38.8	37.1	35.8	31.5	24.6		18.6	(109)
												(*Also* at 35, 50, 60°C)			
	18	81.0	80.0	78.4	76.0	73.2	69.5	62.9	60.0	56.7	50.3	40.1	35.7	30.62	(95, 135, 163)
	25		96	94	90	86	82	75		68	61	52	48	44	(95, 109)
$\frac{1}{2}Sr(MnO_4)_2$	25		117.4	116.5	113.4	110.1									(72)
$\frac{1}{4}Sr_2Fe(CN)_6$	0	59.7	52.5	45.4								19.7	18.5	17.4	(12)
$\frac{1}{2}Ba(OH)_2$	18	219	(217)	(215)	(211)	(207)	200.8	190.6	(185.7)	179.7					(126, 184)
	25	250	(247)	(245)	(240.8)	235.0	226.6	214.6	(209.6)	203.6	191.4				(184, 196)
	50			358	349	341	328	307	(298)	290					(184)
	75					448	427	398	(386)	372					(184)
	100			590	568	547	519	477	(460)	442					(184)
	128					(663)	(614)	548	(523)	502					(184)
	156	(705 at C = 12.5)				(720)	669	592	(562)	530					(184)
$\frac{1}{2}Ba(ClO_2)_2$	25		110.7	108.1	103.9	100.1	95.1	(86.7)							(33)
$\frac{1}{2}Ba(ClO_3)_2$	6										55.3	48.9	46.1	42.5	(47)
	18									79.5	73.8	64.7	61.0	56.4	(47, 95)
	30										93.8	82.0	77.0	70.9	(47)
$\frac{1}{2}Ba(BrO_3)_2$	18		97.4	95.4	91.8	88.1	83.5	(78.2 at C = 40)							(105)
	25		113.4	111.0	106.8	102.6	97.2		(91.0 at C = 40.2)						(105)
$\frac{1}{2}BaS_2O_6$	25		139.1	132.0	120.6	110.5	99.1								(260)
$\frac{1}{2}Ba(NO_2)_2$	20			124	121.4	116.9	110.0	98.2	93.1	87.1					(215.5)
$\frac{1}{2}Ba(H_2PO_2)_2$	25		104.0	101.1	96.8	92.9	88.0	(79.7)							(260)
$Ba(CHO_2)_2$	0		109	108	105	101	95	87	83	79		55			(109)
	18			(For 25, 35°C, *v.* (109))						127.0	111.8	86.76	75.6	62.28	(99)
$\frac{1}{2}Ba(C_2H_3O_2)_2$	0		51	49.7	47.3	45.0	42.6	39.1	37.7	36.1	32.4	(26.5)	24.1	21.4	(109)
	18	86.0	84.9	83.3	80.0	77.0	72.8	65.7	62.7	59.7	53.4	43.60	39.4	34.28	(18, 95, 163)
	25		99	97	92.8	(88.8)	(83.9)	76.0	72.7	69.1	61.8	(50.3)	(45.8)	40.5	(109)
$\frac{1}{2}Ba(C_2H_5CO_2)_2$	18										51.6	41.2	36.9	32.0	(99)
$\frac{1}{2}Ba(MnO_4)_2$	25		114.1	112.0	107.7	103.4	97.6								(72)
$Ba[FeCN)_5NO]$	25		236	225	210	198	186	163							(40)
$Ba(COS)_4Ni$															(223)
$Ba_3Cr_2C_{12}O_{24}$											$3BaC_2O_4.Cr_2(C_2O_4)_3$				(61)
LiOH	18	(For 30, 50, 60°C, *v.* (29); for 25°C, *v.* (206.5))								(180.5)	172.2	156.9	(149.1)	139.0	(29, 97, 126)
$LiClO_3$	18									(74.5)	70.0	62.7	59.5	55.7	(93, 95); *cf.* (48)
	25		101 3	100.4	98.4	96.0	93.3		(For 20°C, *v.* (235))						(195)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$LiClO_4$	0	54.1	53.7	53.3	52.5	51.5	50.3								(263)
	18	87.4	86.9	86.2	84.6	83.0	81.0								(263)
	25		112.8	111.4	108.9	106.5	103.9								(195)
	100	290.6	287.6	284.6	278.6	272.6	264.1								(263)
$LiIO_3$	18	65.78	65.18	64.34	62.80	61.15	58.97	55.18	53.45	51.43	46.81	38.93	35.35	31.17	(93, 129); *cf.* (47, 99)
$LiNO_3$	20														(215.5)
$\frac{1}{2}Li_2CO_3$	18	(63.4 at C = 54) (51.8 at C = 170)													(126); *cf.* (257)
$LiHCO_3$	18											48.0	43.6	38.8	(99)
$LiC_2H_3O_2$	18									51.2	46.2	37.4	33.5	28.7	(95)
$LiC_6H_2N_3O_7$	0	33.6	33.4	33.1	32.4	31.7	30.8				Picrate				(263)
	18	56.9	56.5	56.0	54.8	53.8	52.1								(263)
	100		209.2	207.2	202.2	196.7	190.2								(263)
LiCNS	18											64.3	61.4	57.8	(93)
$LiMnO_4$	25		101.2	98.8	95.8	92.4	89.3								(72)
$\frac{1}{2}Li_2CrO_4$	0		59	57.6	56.2	55.1	53.3	49.0	47.2	45.2	41.0	(*Also* at 15°C)			(267)
	18									74.4	67.5	57.4	53.2	48.3	(93, 95)
	25		111	110.2	108.2	105.4	101.0	92.9	89.2	85.3	77.1				(267)
	35		134	134	132	129	124	113		103.0	93.2				(267); *cf.* (47, 49)
$\frac{1}{2}Li_2Cr_2O_7$	18										73.0	66.0	62.8	58.6	(99)
NaOH	0									(For 10°C, *v.* (209))				104.7	(23)
	18			213.5	210.8	208.4	205.5	200.3	198.0	195.3	189.0	175.5	168.0	158.4	(23, 97, 126, 128, 187, 209)
	25	(*See further* (206.5))				(234.0)	230.0	224.0	221.4	218.2	210.0	(202.5 at C = 300)			(77, 117)
	50													260.6	(23)
	100			581.1			558.5	539.4	(575.7 at C = 4)					406.8	(23, 187)
	156			812.3			769.4	737.1	(803.6 at C = 4) (744.9 at C = 40)						(187)
	218						929	872	(1001 at C = 4) (888 at C = 40)						(187)
$NaClO_3$	0		59.8	59.6	58.9	57.6	56.1	(53.7)	52.6	51.3	(48.3)	(43.6)			(109)
	18	96.3	95.56	94.63	92.8	91.03	88.71	84.65	82.85	80.8	76.43	69.12	65.80	61.8	(48, 69, 95)
	25		(113.0)	111.4	108.8	106.4	103.4	(98.5)		(94.0)	(88.3)	79.5			(69, 109, 195)
	35			134	132	129	125	119		113	106	96			(109
$NaClO_4$	18											71.6	68.6	65	(93)
	25		123.4	121.7	119.1	116.6	113.5	(For 0, 12.5, 35°C, *v.* (109))							(195); *cf.* (109, 261)
$NaBrO_3$	0		56.5	56.0	54.4	53.0	51.2	48.6	47.4	46.1					(267)
	18	89.72	89.09	88.04	86.22	84.4	82.1	78.0	76.1	73.9	69.1	61.7	58.4	54.4	(69, 99)
	25		105	103	100.5	98.8	95.5	90.5	88.2	85.6					(267)
$NaIO_3$	18	75.72	75.08	74.20	72.52	70.76	68.48	64.34	62.50	60.37	55.37				(129)
$\frac{1}{2}Na_5IO_6$	25				171.1	168.3	159.4								(261)
$\frac{1}{2}NaH_4IO_6$	25				20.8	20.5	20.3	19.7	19.4	19.0					(261)
$\frac{1}{2}Na_2H_3IO_6$	25			44.6	43.7	41.7	38.7	33.8	31.8						(261)
$\frac{1}{2}Na_3H_2IO_6$	25				82	81.8	78.8	69.2							(261)
$\frac{1}{2}Na_2S$	0							76.8	76.7	76.4	75.2	(72.2)	(70.7)	68.7	(108)
	18							152	151	149	145	(129)	(120)	110.2	(108); *cf.* (18)
	25							177	174	171	162	143	135	125.8	(108)
	35									155	(153 at C = 150) (146 at C = 300)				(77)
$\frac{1}{2}Na_2S_2$	25		(128 at C = 150) (120 at C = 300) (103 at C = 600)												(77)
$Na_2S_2O_3$	0		133	129	123	119	113	103		93					(267)
	25		254	248	236	226	214	195	187	177	159	(*Also* at 15 and 35°C)			(267)
$Na_2S_2O_4$	0		(102.5 at C = 7.8) (90.6 at C = 31.25) (75.5 at C = 125.0)												(107)
	18		186.1	181.8	(174.0)	166.3	157.7	144.2	138.3	131.5					(107)
	25		(198.3 at C = 7.8) (180.9 at C = 31.25)												(107)
$\frac{1}{2}Na_2S_2O_5$	25				80.9	79.4	75.6								(260)
$Na_2S_2O_6$	25		271	258	245	236	223	201		183	(*Also* at 0, 15, 35°C)				(267)
$\frac{1}{2}NaHS$	0					61.6	60.1	57.9	56.8	55.6	52.7	47.4	45.1	42.5	(108)
	18					92.4	90.7	87.6	86.0	84.1	79.9	72.9	69.6	65.5	(108)
	25					106.7	104.6	100.9	99.1	97.1	92.4	84.2	80.4	76.0	(108); *cf.* (77)
$\frac{1}{2}NaHSO_3$	0		(25.3 at C = 8.7) (23.3 at C = 75.2)												(151)
	25			52.6	50.4	48.2	46.5	44.6	43.9	(*Also* at 50 and 70°C)					(10, 151)
$\frac{1}{2}NaHSO_4$	25		262.8	254.5	236.8	218.5	197.35	168.62	158.5	148.27	130.64				(192); *cf.* (10)
$\frac{1}{2}Na_2SeO_4$	25		119.9	117.3	113.3	109.4	104.1								(261)
$\frac{1}{2}NaHSe$	25			58.8			55.9	(57.4 at C = 4)							(32)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
NaNO	0			65	57	53	49.9	46.2		44.2					(213)
$NaNO_2$	25			121.6	117.8	114.9	111.9	(For 20°C, *v.* (215.5))							(179)
$NaPO_3$	18														(250)
$\frac{1}{3}Na_3PO_4$	0				67.0		59.7			41.6		(*Also* at 15 and 35°C)			(267)
	25				122.2	118.6	111.0					(For 17°C, *v.* (13))			(260)
$\frac{1}{2}Na_4P_2O_7$	0		58.5	57.5	55.1	50.7	(45.8)	(38.7)		33.3	28.2	(*Also* at 35°C)			(267)
	18			99.8	90.2	81.5	72.5	61.4	57.5	53.5	46.2	(41.9 at C = 300)			(1)
	25		114.0	112.3	107.2	99.1	(88.4)	(73.5)		63.5	54.8				(260, 267)
NaH_2PO_2	18		78.1			73.3				64.3		52.0			(5)
	25		(92.9)	92.2	90.2	88.2	85.7	81.4	79.3	76.8	71.3	61.5			(210)
$\frac{1}{3}NaH_2PO_4$	18				22.06	21.95	21.60	20.80	20.40	19.85	18.75	16.88	16.0		(1); *cf.* (13)
$\frac{1}{3}Na_2HPO_4$	0			32.6	32.6	32.2	31.5	29.2	28.0	26.6	23.6	(For 17°C, *v.* (13))			(109)
	18				59.5	57.6	54.8	50.1	48.1	46.0	41.4	(34.5)			(1, 70)
	25			66.7	65.8	64.1	61.3	56.2							(260); *cf.* (109)
	35			85	82.7	79.9	76.3	69.6	66.8	63.8	(*Also* at 50 and 65°C)				(109)
$\frac{1}{2}Na_2H_2P_2O_7$	18		41.1	40.5	39.4	38.2	36.9	34.6	33.6	32.5	29.8	(25.4)			(1)
$\frac{1}{2}Na_3HP_2O_7$	18		72.4	70.1	66.8	63.4	(59.5)	53.3	50.8	48.0	43.0	(35.0)			(1)
$\frac{1}{3}Na(NH_4)HPO_4$	0			37.5	36.6	35.7	34.4	32.2	31.2	29.9	26.5				(109)
	18			62.1	(60.0)	58.3	(55.4)	51.3	(49.4)	47.4	(43.0)	36.2	(33.4)	30.3	(70)
	25				67	66	64	61		59	(*Also* at 35°C)				(109)
$NaAsO_2$	25		96.3	93.2	88.8	85.2	81.0								(261)
$\frac{1}{3}Na_3AsO_3$	25														(261)
$\frac{1}{3}Na_3AsO_4$	25		(128.3)	(127.5)	124.8	118.7	108.7								(261)
$\frac{1}{3}NaH_2AsO_4$	25			(28.3)	27.6	27.1	26.3	25.1	24.6	24.0					(261)
$\frac{1}{3}Na_2HAsO_4$	25			68.0	66.2	63.8	60.7	55.9							(261)
NaH_2SbO_4	25														(252)
$\frac{1}{2}Na_2CO_3$	0			59	56.4	54.4	52.0	47.6	45.8	43.7	39.2	(32.5)	(30.0)	27.0	(109)
	18		112	108.5	102.4	96.1	89.6	80.2	76.7	72.8	(65.0)	54.4	50.2	45.4	(126, 128)
	25				110.7	108.0	103.3	93.6	89.6	85.3	76.3	(63.4)	(58.6)	53.4	(109)
	35			143	137	132	125	115	110	105	93	78			(109)
$\frac{1}{2}Na_2C_2O_4$	25			117.2	113.1	108.7	103.4	95.0	91.7	88.1					(159)
$\frac{1}{6}C_6(CO_2Na)_6$	25				(104.7)	90.8	81.0	70.1	66.2	62.1	Mellitate				(159)
$NaHCO_2$	0		80	79.3	77.6	75.8	73.6	70.3	69.0	67.1	62.2				(267)
	18	89.7	88.6	87.3	85.4	83.6	81.2	76.9	75.0	72.9	68.7	61.3	57.7	53.4	(7, 99)
	25		(150)	149	147.9	145.7	142.0	133.2	129.1	124.4	114.2	(*Also* at 35°C)			(267)
$NaHCO_3$	0			47.7	46.8	45.7	44.2	(41.8)							(124.5)
	12.5			70.1	67.9	66.1	63.7	(59.7)		(For 18°C, *v.* (263.5))					(122)
	25	94.4	93.5	92.5	90.3	88.1	85.5	80.6	78.5	76.1		(95.2 at C = 0.3)			(121, 122)
$NaC_2H_3O_2$	0			44.4	43.9	43.2	41.9	39.9	39.0	38.0	35.4	30.5	(For 10°C, *v.* (157))		(109)
	18	75.87	75.1	74.45	72.60	71.12	69.10	65.58	64.0	62.1	57.57	49.66	45.9	41.16	(95, 126, 128, 148, 178, 183, 188)
	25	(For 50, 65°C, *v.*(109))		87.3	85.5	83.7	81.3	76.9	75.0	72.8	67.7	58.6	54.3	49.1	(109, 157, 225)
	100		274.0	267.0	259.0	252.8	(244.5)	(229.6)	(223.2)	(220.6 at C = 80)					(183)
	156		438.6	423.6	(408)	396.2	(For 89.75°C, *v.* (162))			(339.3 at C = 80)					(183)
	218		627	597		545				(452 at C = 80)					(183)
	306			799		701				(612 at C = 80)					(248)
$NaC_2H_5CO_2$	0	44.7	43.9												(276)
	18		72.4	(71.3)	(69.4)	67.8	(65.8)	(62.2)	60.5	58.4	53.5	45.4	41.6	36.8	(5, 99)
	25		87	85.3	82.7	80.2	77.4	(For 15, 35, 50, 65°C, *v.* (276, 277))							(196, 276)
$NaC_4H_5O_2$	0	(42.1 at C = 0.49)						Crotonate							(276)
	25	(84.1 at C = 0.49)													(276)
	35	(103.3 at C = 0.49)													(276)
$\frac{1}{2}NaC_4H_5O_4$	25		77.8	76.4	73.9	71.6	69.0		Bisuccinate						(196); *cf.* (5)
$NaC_4H_5O_6$	18		119.8	98.8	81.6	74.6	70.0	64.2	62.3	60.3	Bitartrate				(201)
$NaC_3H_7CO_2$	0	43.0	41.8	Butyrate											(276)
	25		82.5	80.5	78.0	76.0	73.4	(75.5 at C = 15.6)							(5, 225, 276)
	35	106	102												(276)
$NaC_4H_7O_3$	0	43.0		Hydroxyisobutyrate											(278)
	15	66.4													(278)
	25	84.5													(278)
	35	100.4	100.7	(*Also* at 50 and 65°C)											(278)

TABLE 2.—(*Continued*)

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_5H_3O_3$						Furancarboxylate									(276)
$NaC_5H_7O_3$	0	34.4			Levulate										(278)
	15	53.4													(278)
	25	68.0													(278)
	35	84.4	101.6						(*Also* at 50 and 65°C)						(278)
$NaC_5H_9O_2$	0	34.4						Isovalerate							(278)
	15	53.4													(278)
	25	68.0													(278)
	35	84.4	101.5					(*Also* at 50 and 65°C)							(278)
$NaC_7H_5O_2$	0	41.4						Benzoate							(276)
	14.5	64.1													(276)
	25	82.7	81.9	80.8	78.8	76.9	74.5								(145, 276)
	35	102.2													(276)
$NaC_7H_5O_3$	0	43.2	42.6					*o*-Hydroxybenzoate							(276)
	25	85.0	83.7	82.0	79.6	77.7									(148, 276)
	35	105	102												(276)
$NaC_7H_5O_3$	35	105.3						*m*-Hydroxybenzoate							(278)
	50	136													(278)
	65	170													(278)
$NaC_7H_5O_3$	20		69.6	68.7	67.3	65.2	62.7	*p*-Hydroxybenzoate							(36)
	25		(79.3)	77.5	74.6	72.5									(148)
	35		105					(*Also* at 50 and 65°C)							(278)
$NaC_7H_5O_4$	35		101.3					2, 4-Dihydroxybenzoate							(278)
	50		130.5												(278)
	65		163												(278)
$NaC_7H_5O_5$	0	40.4						Gallate							(276)
	25	79.1													(276)
	35	97.7													(276)
$NaC_8H_7O_2$	25		81.4	79.9	77.3	74.9	72.4	*o*- *m*- *p*-Toluate and Phenylacetate							(195); *cf.* (225)
$NaC_8H_7O_3$	25		82.2	80.1	77.2	75.0	*o*- and *p*-Hydroxymethylbenzoate								(147)
$NaC_8H_7O_3$							Mandelate (At 0, 25, 35°C)								(276)
$NaC_8H_7O_3$	25			78.6	(76.2)	74.0	71.3	*o*- and *p*-Methoxybenzoate							(147)
$NaC_8H_{15}O_2$								Caprylate (At 0, 25, 35, 50, 65°C)							(277, 278)
$NaC_9H_7O_2$							Phenylacrylate (At 0, 25, 35°C)								(276)
$NaC_{14}H_{11}O_3$	0	38.7	37.4					Diphenylglycolate							(277, 278)
	25	76.0	69.9												(277, 278)
	35	94.5	91.7												(277, 278)
$NaC_{16}H_{31}O_2$	89.7	Palmitate (*see also* Vol. V, p. 458)				135		86		79	77	77		65	(162)
$\frac{1}{2}Na_2C_3H_2O_4$	25			107.4	103.9	100.0	95.3		Malonate						(159)
$\frac{1}{2}Na_2C_4H_4O_4$	25	Succinate		100.7	97.7	94.3	90.1	83.4	80.6	77.6	71.1	60.5	56.0	50.5	(159)
$\frac{1}{2}Na_2C_4H_2O_6$	25			105	103	99	95	Dihydroxymaleate							(152)
$\frac{1}{2}Na_2C_4H_4O_6$	25	Tartrate		*dl* (97.2s at $C = 7.81$)			*l* (97.6 at $C = 7.81$)			*d* (98.2s at $C = 7.81$)					(225)
$\frac{1}{2}Na_2C_8H_4O_4$	25			96.5	93.0	89.5	85.2	77.7	74.6	71.4		Phthalate			(159)
$\frac{1}{2}Na_2C_8H_4O_4$	25		97.8	95.9	92.6	89.5	85.6	79.4	(76.8)			Isophthalate			(159)
$\frac{1}{2}Na_2C_8H_4O_4$	25			95.2	92.0	89.05	85.25					Terephthalate			(159)
$\frac{1}{4}Na_4C_{10}H_2O_8$	25		120.0	116.1	108.3	101.1	93.2	82.4	78.5	Pyromellitate (1, 2, 4, 5)					(159)
$Na_4C_{11}H_2O_{10}$	0	232.4	216.8	200.5	177.9	160.5	143.5	120.4		Benzenepentacarboxylate					(190)
	25	455	426.8	395.4	349.4	314.0	281.5	240.0							(190)
	50	729	679	628	553	497	445	379							(190)
$Na_5C_{11}HO_{10}$	0		278.0	(253)	217.8	177.4	154.6	141.2	Benzenepentacarboxylate						(190)
	25		538.8	488.0	419.2	371.0	329.0	278.2	(577 at $C = 0.6$)						(190)
	50			764	634	562	505	434	(914 at $C = 0.6$)						(190)
$NaCH_2ClCO_2$	25			88.05	85.37	82.90	80.20	76.05	74.35	72.24	66.60				(59)
$NaCHCl_2CO_2$	18		73.3			68.8	(66.6)	(63.0)		59.4	(54.7)	48.0			(6)
$NaC_4H_4Cl_3O_2$	25		76.8	75.7	73.9	72.2	70.0			Trichlorobutyrate					(121); *cf.* (210)
$NaC_8H_4ClCO_2$	0		40.5							*o*-Chlorobenzoate					(276)
	15		62.8												(276)
	25	81.5	80.7	79.6	77.7	75.7	73.2								(121)
	35		99.3												(276)
$NaC_8H_6ClO_2$	25		79.6	78.0	75.5	73.3	(70.1)			(*Also* at 50 and 60°C) Phenylchloroacetate					(240)

TABLE 2.—(*Continued*)

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_3H_4BrO_2$	0	47.7	44.7							α-Bromopropionate					(278)
	25	95.3	89.6												(278)
	35	115	112												(278)
$NaC_3H_6Br_2O_2$		(At 0, 15, 25, 35°C)								α, β-Dibromopropionate					(278)
$NaC_4H_4BrO_2$	0	45.1	44.1							α-Bromobutyrate					(278)
	15	69.2	68.3												(278)
	25	87.7	87.2												(278)
	35	109.2	107.5												(278)
$NaC_3H_4IO_2$		(At 0, 15, 25, 35°C)								β-Iodopropionate					(278)
$NaC_6H_5SO_4$	25			80.6	78.3	76.0				o-Phenolsulfonate					(147)
$NaC_6H_5SO_4$	25		80.9	79.4	76.9	74.5				p-Phenolsulfonate					(147)
$NaC_{10}H_7SO_3$	25				76.1	74.5	72.3	68.6	66.8	64.7	β-Naphthalenesulfonate				(210)
$NaC_{16}H_{33}SO_3$		(At 40, 50, 60. 65°C)		(*see also* Vol. V, p. 458)							Cetylsulfonate				(220)
$NaC_{14}H_8BrSO_3$							10-Bromophenanthrene-3(6)-sulfonate								(237)
$NaCHN_2$	25					116	108.2	98.4	95.1	91.7	Bicyanamide				(117)
NaC_7H_8N	18		72.4	71.7	69.9	67.9	65.5				o-Toluidine				(160)
$NaC_3H_2NO_2$	25	87.7	86.9	85.6	83.8	81.9	79.3	74.7	72.9		$CH_2.CN.CO_2Na$ (At 0, 25, 35, 50, 65°C (278))				(119, 121); *cf.* (210, 225)
$NaC_3H_3N_4O_2$									N-Methyltetrazolecarboxylate						(194)
$NaC_5H_3N_4O_3$											Urate				(73)
$NaC_6H_2N_3O_7$	18					64.8		60.4	Picrate						(80, 118)
	25		82.4	81.1	79.1	77.3	74.8								(118, 196)
$NaC_7H_4NO_4$	25	82.9	81.2	79.5	77.1	75.1	72.5	68.0	(66.2)	o-Nitrobenzoate					(119, 121)
	35		101.3	o and m-Nitrobenzoate											(278)
$NaC_7H_4NO_4$	50		132.4		m-Nitrobenzoate										(278)
	65		166												(278)
$NaC_7H_4NO_4$	0	42.4	41.4		p-Nitrobenzoate										(277)
	25	81.4	80.6												(277)
	35	102.0	99.3					(For 50, 60°C, *v.* (277, 278))							(277)
$NaC_7H_6NO_2$	0	40.7						o-Aminobenzoate							(276)
	25	80.7													(276)
	35	98.5													(276)
$NaC_7H_3N_2O_6$	35		99.1								1, 2, 4-Dinitrobenzoate				(278)
	50		128.9												(278)
	65		161.5												(278)
$NaC_7H_3N_2O_6$	25	77.9	77.2	76.1	74.3	72.5	(70.4)				1, 3, 5-Dinitrobenzoate				(119, 121)
	35		99.3								(*Also* at 50 and 65°C)				(278)
$NaC_9H_8NO_3$	0	38.5	37.9								Hippurate				(276)
	25	76.2	75.3												(276)
	35	93.6	92.3												(276)
$NaC_{10}H_6NO_2$	25	α-Cyanocinnamate				78.8	78.2	77.3	77.1	76.6	75.4	72.7	71.0	68.9	(252)
NaCNS	0		61	61.4	59.8	58.8	57.4	55.2	54.3	53.3	50.7	(*Also* at 25 and 35°C)			(267)
	18											74.2	71.9	68.8	(93, 267)
$NaC_6H_4NSO_5$	25	m-Nitrobenzenesulfonate						72.3		67.9	62.1				(77)
$NaC_6H_6NSO_3$	0	42.0	40.9								o-Aminobenzenesulfonate				(276)
	25	82.7	81.1												(276)
	35	102	100		(*Also* at 11.9°C)										(276)
$NaC_6H_6NSO_3$											p-Aminobenzenesulfonate				(248.5)
$NaC_7H_6NSO_4$	35	99.6									p-Sulfaminobenzoate				(278)
	50	131.2													(278)
	65	164													(278)
$Na_2C_{32}H_{22}N_6S_2O_6$	18		73.3	68.7	59.6	53.3					Congo red				(21)
	25		171	159.6	137.8	123.8	112.5								(63)
$NaC_9H_{12}PO_2$											Mesitylenephosphinite				(52)
$\frac{1}{2}Na_2C_3H_7PO_6$	0	Glycerophosphate				47.6	46.4	43.5	41.4	38.1	29.7				(9)
$NaC_6H_4AsCl_2O_4$	18		84.2	79.0	74.7	71.5	68.1				Dichlorophenolarsenate				(160)
$NaC_6H_7As_2O_6$	18		300	234	163.5	127.0	101.0				p-Phenylenediarsenate				(160)
$Na_2C_6H_3AsCl_2O_4$	18		179.2	174.7	166.2	157.6					Dichlorophenolarsenate				(160)
$Na_2C_6H_6As_2O_6$	18		139.1	117.5	95.7	84.3	76.1				p-Phenylenediarsenate				(160)
$NaC_6H_4AsBr_2O_4$	18	93.0	85.4	79.8	75.1	70.2	66.9				Dibromophenolarsenate				(160)
$Na_2C_6H_3AsBr_2O_4$	18	176	170.0	166.1	160.5	152.0					Dibromophenolarsenate				(160)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_6H_5AsNO_6$	18	80.3	77.4	74.6	71.5	69.2	66.6				3-Nitro-4-hydroxyphenylarsenate				(160)
$NaC_6H_7AsNO_3$	18		71.7	71.2	69.9	68.6	66.5				$NaC_6H_4(NH_2).AsO(OH).O$				(160)
$NaC_6H_4AsN_2O_8$	18	259	217.7	183.2	146.2	124.4	116.2				Dinitrophenolarsenate				(160)
$NaC_6H_6AsN_2O_5$	18		73.7	73.0	71.8	70.6	68.0				3-Nitro-4-aminophenylarsenate				(160)
$NaC_6H_8AsN_2O_3$	18		71.2	70.8	69.8	68.3	66.1				*o*-Phenylenediaminearsenate				(160)
$NaC_8H_{11}AsNO_3$	18		72.7	71.8	70.6	69.1	66.7				Dimethylaminophenylarsenate				(160)
$Na_2C_6H_4AsNO_6$	18	169.2	168.4	167.5	163.0	155.4					3-Nitro-4-hydroxyphenylarsenate				(160)
$Na_2C_6H_5AsN_2O_5$	18		173.8	171.3	163.0	155.4					3-Nitro-4-aminophenylarsenate				(160)
$Na_3C_6H_3AsNO_6$	18		290.9	281.4	261.2	244.5					3-Nitro-4-hydroxyphenylarsenate				(160)
$Na_3C_6H_2AsN_2O_8$	18		289.6	279.7	261.8	243.4					Dinitrophenolarsenate				(160)
$\frac{1}{3}Na_2SiO_2$	18		144		139	136		124		116		87.5		71.4	(95, 128)
	25	(*Also* other compounds)			158.5	155.5		143.8		130.8	112.7	96.8		81.2	(91)
$\frac{1}{3}Na_2Hg(SO_3)_2$	25		112.7	109.3	104.2	100.0	95.1								(10)
Na_2HgNO_2															(215.5)
$\frac{1}{3}Na_2Pt(CN)_4.7H_2O$	25		130.1	127.4	123.2	119.2	114.2								(261)
$NaMnO_4$	25		112.5	111.2	108.6	105.7	(102.3)								(72)
$NaFe(ClO_4)_4.6H_2O$															(271)
$\frac{1}{4}Na_4Fe(CN)_6$	0		73.8	70.8	66.4	62.2	57.5	51.1	48.7	46.2	41.6	35.4	(*Also* at 35, 50, 65°C)		(109)
	25	151	145.8	140.3	129.4	119.9	109.9	96.8	92.4	88.0	79.9				(185)
$Na_4Fe(CN)_6.10H_2O$															(39)
$Na_2[Fe(CN)_5NO]$	25		236	229	220	211	202	188	181	174					(40); *cf.* (61)
$Na_3Co(NO_2)_6$															(61, 242)
$Na_2NiC_{12}H_{12}O_8$											Dipyrocatechinodiaquonickelate				(219)
$\frac{1}{2}Na_2CrO_4$	0			62	61.6	60.1	57.7	53.8	51.6	49.6	45.8	39.8	(*Also* at 15°C)		(267)
	18									82.1	75.8	66.3	62.4	57.8	(95); *cf.* (47)
	25			118	115.5	112.4	108.4	100.9	97.5	93.7	85.9				(267)
	35					(138)	132	122	118	114	103				(267)
$\frac{1}{2}Na_2Cr_2O_7$	0				57.0	56.6	56.0	54.5	53.6	52.5	50.0	(*Also* at 15°C)			(267)
	25				103		102.0	98.8	96.6	94.9					(267)
	35				125		123	117	115	113.6					(267)
$\frac{1}{3}Na_2MoO_4$	25		120.5	117.5	113.3	109.4	104.0								(260)
$\frac{1}{6}Na_5Mo_6H_{17}O_{24}$		$Na_5H_5[H_2(MoO_4)_6].15\frac{1}{2}H_2O$													(226)
$\frac{1}{3}Na_2[P(Mo_2O_7)_3]$															(230)
$\frac{1}{2}Na_2WO_4.2H_2O$	0			57.9	56.4	54.5	51.9	47.8	46.0	44.0	39.0	31.7			(267)
	25		116.1	113.4	109.2	104.8	99.8	92.2	89.2	85.8					(260, 267)
	35			136	134	129	123	112		104	95	(*Also* at 15°C)			(267)
$\frac{1}{3}Na_2B_2O_4.8H_2O$	25		88.9	86.7	83.2	80.1	76.2			Metaborate					(260)
$\frac{1}{2}Na_2B_4O_7$	0		43.2	42.3	41.0	39.3	38.1	34.9	33.6	32.1	(*Also* at 35, 50, 65°C				(109)
	25		86.0	84.4	81.5	78.6	75.1	(69.3)							(260)
$Na_5BW_{12}H_4O_{42}$										$\frac{1}{3}Na_5H_4[B(W_2O_7)_6].27H_2O$					(229)
$Na[Al(ClO_4)_4].12H_2O$															(271)
KOH	18		234	233	230	228	224	218	216	213	207	197	192	184	(97, 126, 128)
	30	(For 25°, *v.* (206.5))		(*Also* at 20, 45, 60, 75°C)				270	269	267	262	248	241	233	(78)
	90							519		507	492	461	447	(431)	(78)
KHF_2	25		270	217	167	150	138								(261)
$KClO_2$	25		124.0	122.2	119.5	117.2	114.2								(33)
$KClO_3$	0	73.8	74.3	73.4	72.2	71.0	68.8	65.4	64.0	62.6					(109, 263); *cf.* (116, 140)
	18	117.50	116.74	115.67	113.67	111.47	108.65	103.58	101.45	99.04	93.59				(138, 263)
	25		135.7	134.4	132.0	129.6	125.7	119.2	116.4	113.8	(For 50, 65°C, *v.* (159))				(109)
	35		162	161	158	154	150	142		135					(109)
	100	360.0	359.0	356.0							(For 95°C, *v.* (116, 140))				(263)
$KClO_4$	0	76.3	75.9	75.3	74.0	72.6	70.5								(263); *cf.* (109)
	18	120.6	118.8	118.5	116.4	114.0	110.9	105.5							(263)
	25		139.1	137.8	134.4	131.7	127.5								(109); *cf.* (181, 195)
	35		166	164	161	158	153		(*Also* at 50 and 65°C)						(109)
	100	369.0	366.5	362.0	355.0	347.0	336.0								(263)
$KBrO_3$	0		69.7	69.1	67.8	64.9									(263)
	18		109.7	108.5	106.7	104.5	101.9	97.2	95.1	92.9	87.7				(105, 263)
	25		126.7	125.6	123.4	120.8	117.6	112.2	109.8	107.0	101.0				(105, 261)
	100		340.5	337.0	331.0										(263)

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
KIO_3	0	60.0	59.8	59.2	58.0	56.9									(263)
	18	96.58	95.90	94.91	93.07	91.11	88.51	83.94	81.87	79.56	74.23	(95.293 at C = 1.4934) (141)			(129, 263)
	25	112.21	111.41							(110.694 at C = 1.4910(141))					(90)
	100	315.0	312.5			293.1									(263)
$\frac{1}{2}K_2S$	18												138.6	135.4	(18)
$\frac{1}{2}K_2SO_3$	25		143.2	139.5	133.9	129.2	123.6	114.0	110.1	105.9	97.7	86.4	82.2	77.8	(10)
$\frac{1}{2}K_2S_2O_8$	25		153.2	150.2	145.1	139.9	132.2								(27)
$\frac{1}{2}KHS$	18		(46.4)	45.9	41.7	34.7	19.7								(18)
$\frac{1}{2}KHSO_3$	25			64.8	62.4	60.4	58.2	55.0	53.8						(10)
$KHSO_4$	0			(310)	291	273	252	222	211	200	183	164			(109)
	18			455.3	(414)	378.3	(341)	295.0	(278.8)	263.2	234.2	204.0	194.8	186.0	(126, 184)
	25			505.4	(456)	416.3	(374)	317.7	(300)	282.6					(184); *cf.* (109)
	50			659.8	(571)	507.1	(446)	373.7	(351)	328.5					(184); *cf.* (109)
	75			752.7		557.0	(476)	402.1	(377)	353.8					(184)
	100			782.6		579.0	(504)	421.4	(397)	373.9					(184)
	128			771.7		598.9	(526)	445.2	(423)	401.3					(184)
	156			752.6		609.9	(548)	476.1	(455)	434.2					(184)
KN_3	0													59	(30)
KNO_2	25		166	161.6	157.0	153.5	150.0		(For 20°C, *v.* (215.5))						(179)
KPO_3	20														(250)
$\frac{1}{3}K_3PO_4$	0				68.0	66.7	64.8	57.8	54.2	50.4		(*Also* at 35 and 65°C)			(109)
	25				129	128	125	113	106	98		(For 17°C, *v.* (13))			(109)
$\frac{1}{3}KH_2PO_4$	0			15	15.0	14.6	14.2	13.5	13.2	12.8	11.8	(*Also* at 35°C)			(267)
	18		31.7		30.1	29.5	(28.7)	27.7	27.1	26.5	(25.3)	23.2	22.4	21.4	(70, 126)
	25			29	28.4	27.8	27.0	25.6	25.1	24.4	22.7				(260, 267)
$\frac{1}{3}K_2HPO_4$	0	(*Also* at 25, 35°C; for 17°C, *v.* (13))		(39)	38.5	37.6	36.5	34.5	33.5	32.5	(30.4)	(26.9)	(25.6)	(24.1)	(109)
$\frac{1}{3}KH_2AsO_4$	25			(35.6)	35.0	34.4	33.6	32.3	31.7	31.2					(261)
KH_2SbO_4	25														(252)
$K_3Bi(S_2O_3)_2.1.5H_2O$															(61)
$\frac{1}{2}K_2CO_3$	0	(*Also* at 50 and 65°C)			69.0	66.9	64.4	60.5	58.9	57.1	53.6	(48.6)	(46.6)	44.9	(109)
	18		133	128	121.4	115.3	(109.2)	100.6	(97.5)	94.0	(87.3)	77.7	(74.2)	70.6	(126, 128)
	25				131.8	127.5	122.4	114.2	110.8	107.9	99.1	(88.2)	(84.2)	80.0	(109)
	35				150	144	138	127	122	117				84	(109)
$\frac{1}{2}K_2C_2O_4$	0			74.8	(72.3)	70.0	67.3	62.9	61.1	59.2	55.7				(186)
	18	123.63	122.25	120.28	116.55	112.66	107.91	100.62	97.80	94.65	88.55	80.25	77.00	73.52	(126, 133)
	25			139.0	(135.0)	130.7	125.0	116.3	112.9	109.3	102.1				(186)
$\frac{1}{2}KHCO_3$															(126)
$\frac{1}{2}KHC_2O_4$	18	216.9	183.2	160.8	134.5	121.6	109.8	96.4	92.5	88.9					(65)
$KC_2H_3O_2$	0	63.1	62.0	60.9	59.5	(58.4)	57.8	55.0	53.9	52.6	50.0	(*Also* at 50 and 65°C)			(109)
	18	98.8	98.2	97.3	95.6	93.8	91.5	87.8	86.2	84.4	79.6	70.7	66.8	62.4	(18, 93, 128)
	25	115.8	113.7	112.1	109.8	108.0	105.6	100.8	98.8	96.8	90.7	(For 90°C, *v.* (38))			(109)
	35	138	137	136	133	131	128	121	118	115	108				(109)
$KHC_4H_4O_6$	18		142	120	101	93	86.8								(201)
$KC_6H_{11}O_2$	90	Hexoate (*See* Vol. V, p. 458)													
$KC_8H_5O_4$	25	128.8	119.3	111.6	103.7	99.9	95.5	89.3		83.8	76.8	Biphthalate			(200)
$KC_7H_5O_3$	25		101.7	100.1	98.0	95.9						*p*-Hydroxybenzoate			(148)
K-Soaps	(*See* Vol. V, p. 458)														
$\frac{1}{2}K_2C_8H_4O_4$	25		121.8	120.3	116.2	112.1	107.1	99.1	95.8	92.2		Phthalate	(123.3 at C = 0.4)		(200)
$\frac{1}{3}K_3(C_6H_5O_7)$	0			70.9	67.5	63.8	(59.7)	54.3	52.4	50.1	43.4	Citrate			(186)
	18	119.9	(117.7)	115.2	109.7	101.6	(95.2)	87.7	84.3	80.7					(186)
	25	139.2	(137.0)	134.3	128.0	118.5	(111.0)	101.9	98.1	93.8					(186)
$KC_2Cl_3O_2$	25		106.6	104.7	101.7	99.2	96.3	91.6	90.0	87.5	82.5	74.6	Trichloroacetate		(121)
$KC_2HCl_2O_2$*	25		108.7	106.8	104.2	102.1	99.7	95.5	93.5	91.4	86.6	77.7	73.4	68.5	(121)
$K_2C_2H_6TeO_4$										$K_2[H_6TeO_6.C_2O_4]$					(231)
KCN	18	(104.0 at C = 506) (9.7 at C = 1029)													(126)
$KCNO$	18														(178)
$KC_6H_2N_3O_7$	0	54.6	54.3	53.8	52.8	51.0			Picrate						(263)

* Dichloroacetate.

TABLE 2.—(*Continued*)

Solute	°C \ C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$KC_6H_2N_3O_7$.—(*Continued*)	18	88.1	87.4	86.6	85.0	83.3	81.0								(263)
	100		282.1	279.1	272.6	271	258.1								(263)
$KC_{10}H_6NO_3$	25	α-Cyanocinnamate				96.0	95.2	94.1	93.6	93.0	91.7	88.7	86.7	83.8	(252)
$KC_7H_6NSO_5$	25		102	100	98.0	(96.1)			Nitrotoluenesulfonate						(102)
KCNS	0		76.9	76.7	75.8	74.7	72.9	69.8	68.6	67.8	64.8	61.8	(*Also* at 50 and 65°C)		(109)
	18	119.10	118.36	117.39	115.55	113.69	111.33	107.50	106.10	104.5	101.9	95.48	93.7	91.41	(93, 138)
	25		139.9	138.8	136.9	134.4	130.8	124.9	122.5	119.8	(114)	(For 25.7°C, *v.* (17))			(109)
	35			163	160	157	154	149	147	144	138				(109)
$K_3Sb(C_2O_4)_3.H_2O$															(61)
$\frac{1}{2}K_2Hg(SO_3)_2$	25		134.0	130.8	125.7	121.0	115.1								(10)
$\frac{1}{2}K_2HgN_4O_8$									$\frac{1}{2}2KNO_2.Hg(NO_2)_2$						(214)
$K_2[Pt(NO_2)_4]$	25														(46)
$KMnO_4$	25	133.9	133.0	131.7	129.5	127.4	124.1	118.7	116.2	113.6	(For 0, 35, 50, 65°C, *v.* (109))				(27, 156); *cf.* (109)
$KFe(SO_4)_2.H_2O$															(271)
$K_3FeC_{18}H_{15}O_7$	18		320	295	264	(249 at $C = 8$)			Tripyrocatecholaquoferrate						(219)
$\frac{1}{3}K_3Fe(CN)_6$	0		89.1	86.2	82.0	78.6	74.6	68.6	66.4	63.9	59.6				(267); *cf.* (51)
	18											86.4		82.0	(99); *cf.* (39)
	25	167	162.1	158.5	150.8	143.9	135.8	123.8	119.5	115.1	106.9	97.3			(261, 267)
	35		197	191	181	172	162	148	143	138	127				(267); *cf.* (123)
$\frac{1}{4}K_4Fe(CN)_6$	0	91.5	(87.0)	84.7	(78.5)	72.8	(66.8)	58.1	55.4	52.9	48.7				(186); *cf.* (109)
	18			136.8	(122.9)	113.2	(103.9)	92.6	88.8	85.1	78.8	71.1	68.9	66.6	(99, 186); *cf.* (39, 140)
	25	172.8	166.8	160.0	146.8	135.2	123.2	108.2	103.1	98.1	89.7	80.9	78.9	77.14	(185, 239); *cf.* (109)
	35	(*Also* at 50, 65°C)	186.9	181.6	172.7	162.8	(148.9)	130.3	124.2	117.9	107.7	97.0	93.9	90.9	(109)
$K_2[Fe(CN)_5NO]$	25		256.3	250.0	240.8	232.4	222.2	208.4							(40)
$K_3Co(NO_2)_6$															(61)
$K_3CoC_{18}H_{15}O_7$	18		342	312	272	(252 at $C = 8$)			Tripyrocatecholaquocobaltate						(219)
$K_4CoC_{18}H_{14}O_7$	18		480	443	397	(378 at $C = 8$)			Tripyrocatecholhydroxycobaltate						(219)
$K_3(COS)_6Co$	25					348	319		Cobaltidithiooxalate						(223)
$K_3Co(CN)_6$															(39, 61)
$KCoC_9H_{14}N_5O_6$															(42)
$K_2Co(CNS)_4$															(61)
$K_2Ni(CN)_4$															(123)
$K_2Ni(COS)_4$															(223)
$\frac{1}{2}K_2CrO_4$	0		80.6	79.7	77.8	76.0	73.6	68.9	66.9	64.7	60.4	54.5	52.4	51.3	(109)
	18									100.4	94.3	86.4	83.1	79.4	(93)
	25		149.0	147.2	143.5	138.7	132.7	123.8	120.3	116.3	107.7	88.2			(109); *cf.* (260)
	35		178	176	173	166	159	147		139	129	105	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}K_2Cr_2O_7$	0		72.4	71.6	70.3	69.5	68.4	66.1	64.8	63.1	59.5	(*Also* at 50 and 65°C)			(109)
	18									98.1	93.0	85.3			(99)
	25		130.5	128.0	125.7	124.2	122.5	118.2	116.0	113.2	106.7				(109, 260)
	35		156	152.7	149.0	148.2	146.8	141.0	137.9	134.5	127.1				(109)
$K_3Cr(C_2O_4)_3$															(123)
$\frac{1}{3}K_3Cr(CN)_6$	25		171.6	166.9	159.9	153.4	145.5	(For 18°C, *v.* (39))							(261)
$\frac{1}{3}K_3W(CN)_8$	1		89.9	87.9	83.8	79.5	75.0	68.7	66.5						(51)
$K_3Cr(CNS)_6.4H_2O$															(61)
$\frac{1}{4}K_4Mo(CN)_8.2H_2O$															(227)
$K_3H_6[Fe(MoO_4)_6].7H_2O$															(229)
$K_3H_6[Cr(MoO_4)_6].7H_2O$															(229)
$\frac{1}{4}K_4W(CN)_8.2H_2O$															(227)
$\frac{1}{4}K_4H_5[Fe(WO_4)_6].9H_2O$															(229)
$\frac{1}{2}K_2B_2O_4$	0					53.0	50.6	49.3	47.8	44.4	Metaborate				(168)
$\frac{1}{2}K_2B_4O_7$	0					52.2	49.3	47.7	45.6	40.8					(228)
	25	123	114	105	101	98	91								(228)
$\frac{1}{2}K_2B_{10}O_{16}.8H_2O$	0	(59)	58	56	53.6	50.7	45.1								(228)
	25	(120)	116	110	105	100	89								(228)
$KAl(SO_4)_2$															(123)
$K_3H_6[Al(MoO_4)_6].7H_2O$															(229)
$K_2CaFe(CN)_6.3H_2O$															(61)
$K_2BaFe(CN)_6.3H_2O$															(61)
$\frac{1}{2}KNaSO_3$	25	125.3	123.9	119.3	114.4	108.9									(10)
RbOH	18	(For RbOH and CsOH at 25°C, *v.* (206.5))							220.2	213.3	202.8	197.1	189.4		(97)

TABLE 3.—(*Continued from p. 241*)

⅓H_3PO_4.—(*Cont'd*)

C	$10^6\kappa/C$
14 700	9.3
22 000	6.3
33 700	2.3
39 600	1.2
50 400	0.44
57 700	0.24

H_3PO_4, 18°

1 076	52.53
1 658	51.18
3 613	45.72
5 930	35.13
7 716	25.59
10 820	13.23
15 086	4.662

$NH_4C_2H_3O_2$, 18°

2 000	42.7
3 000	33.8
4 000	26.5

NH_4CNS, 18°

2 000	84.6
3 000	79.1
4 000	73.9

½$Pb(C_2H_3O_2)_2$, 18°

2 000	3.85
3 000	2.52

½$Zn(ClO_3)_2$, 18°

2 000	44.0
3 000	35.4
4 000	28.7

½$Zn(BrO_3)_2$, 18°

2 000	32.3
3 000	24.2

½$Cd(ClO_3)_2$, 18°

2 000	43.6
3 000	34.6
4 000	27.3

½$Cu(ClO_3)_2$, 18°

2 000	43.5
3 000	34.5

½$Co(ClO_3)_2$, 18°

2 000	43.7
3 000	35.1
4 000	27.9
5 000	21.6

½$Ni(ClO_3)_2$, 18°

2 000	43.6
3 000	34.6
4 000	27.5

⅓H_3BO_3, 18°

1 409	0.015
1 777	0.0175

½$Mg(ClO_3)_2$, 18°

2 000	44.3
3 000	35.6
4 000	28.4

½$Mg(BrO_3)_2$, 18°

2 000	34.0
3 000	25.6

½$Mg(C_2H_3O_2)_2$

C	$10^6\kappa/C$
18°	
2 000	14.8
3 000	8.8
4 000	4.85
5 000	2.61
6 000	1.30
6 550	0.770
7 744	0.218
25°	
2 000	17.4
3 000	10.4
5 000	3.41
6 550	1.08
7 744	0.333

½$MgCrO_4$, 18°

2 000	28.00
3 000	21.55
4 000	16.20
5 000	11.90

½$Ca(ClO_3)_2$

6°	
2 000	32.1
3 000	24.9
4 000	19.3
18°	
2 000	49.9
3 000	41.0
4 000	(33.7)

½$Ca(C_2H_3O_2)_2$, 18°

2 000	15.6
3 000	9.40

½$Ca(C_2H_5CO_2)_2$

18°	
2 000	13.0
3 000	6.70

¼$Ca_2Fe(CN)_6$, 0°

2 000	15.7

½$Sr(ClO_3)_2$, 18°

2 000	46.9
3 000	37.6

½$Sr(BrO_3)_2$, 18°

1 500	39.9

½$Sr(CHO_2)_2$, 18°

1 500	35.3

½$Sr(C_2H_3O_2)_2$, 18°

2 000	19.13
3 000	11.85

¼$Sr_2Fe(CN)_6$, 0°

2 000	15.3

½$Ba(ClO_3)_2$

C	$10^6\kappa/C$
6°	
1 500	37.9
2 000	(34.4)
18°	
2 000	44.7
30°	
1 500	62.4
2 000	(55.7)

½$Ba(C_2H_3O_2)_2$, 18°

2 000	22.43
3 000	(14.8)
4 000	9.20

½$Ba(C_2H_5CO_2)_2$

18°	
2 000	18.7

LiOH

18°	
2 000	113.3
3 000	94.4
4 000	78.7
5 000	(65.3)
30°	
1 955	112.3
4 535	71.2
50°	
1 933	184.7
4 483	127.6
60°	
1 925	206.6
4 465	145.6

$LiClO_3$, 18°

2 000	46.9

$LiIO_3$, 18°

2 000	21.3
3 000	14.4

$LiCHO_2$, 18°

2 000	27.5
3 000	(19.9)
4 000	14.0

$LiC_2H_3O_2$, 18°

2 000	18.2
3 000	11.7
4 000	7.40

LiCNS, 18°

2 000	48.33
3 000	40.0

½Li_2CrO_4, 18°

2 000	37.4
3 000	29.8
4 000	23.3

½$Li_2Cr_2O_7$, 18°

2 000	47.6

NaOH

0°	
2 000	(84.0)
3 000	66.9
4 000	52.9
5 000	40.7
6 000	30.5

NaOH.—(*Cont'd*)

C	$10^6\kappa/C$
7 000	22.6
8 000	16.3
9 000	11.9
10 000	8.60
11 000	6.30
12 000	4.55
13 000	3.40
14 000	2.60
15 000	2.00
16 000	1.65
17 000	1.34
18 000	1.10
19 000	0.900
18°	
2 000	129.4
3 000	104.2
4 000	86.7
5 000	68.9
6 000	54.2
7 000	43.0
8 000	33.85
9 000	26.3
10 000	20.5
11 000	16.3
12 000	12.9
13 000	10.48
14 000	8.70
15 000	7.35
16 000	6.37
17 000	5.60
18 000	4.95
19 000	4.40
50°	
2 000	(218.2)
3 000	184.9
4 000	158.2
5 000	133.9
6 000	112.9
7 000	94.8
8 000	80.4
9 000	67.9
10 000	57.5
11 000	49.2
12 000	42.4
13 000	36.8
14 000	32.6
15 000	29.3
16 000	26.7
17 000	24.3
18 000	22.2
19 000	20.5
100°	
2 000	(347)
3 000	304.4
4 000	276.0
5 000	247.0
6 000	220.2
7 000	196.6
8 000	175.7
9 000	156.9
10 000	140.6
11 000	126.6
12 000	115.1

NaOH.—(*Cont'd*)

C	$10^6\kappa/C$
13 000	104.9
14 000	96.2
15 000	88.7
16 000	82.3
17 000	76.4
18 000	77.5
19 000	67.7

$NaClO_3$, 18°

2 000	51.7
3 000	43.5
4 000	36.1

$NaClO_4$, 18°

2 000	54.97
3 000	46
4 000	38.70

$NaBrO_3$, 18°

2 000	44.0

½Na_2S

0°	
2 000	58.8
3 000	47.5
4 000	37.0
18°	
2 000	89.7
3 000	73.5
4 000	60.5
25°	
2 000	103.2
3 000	86.0
4 000	71.0

½NaHS

0°	
2 000	35.9
18°	
2 000	56.6
25°	
2 000	65.7

NaN_3 (30, 194)

0°	
1 500	39.4
2 000	36.2
3 000	30.7
4 000	25.3
5 000	(20.6)
25°	
1 500	69.6
2 000	64.8
3 000	56.3
4 000	46.4
35°	
1 500	83.7
2 000	77.0
3 000	65.7
4 000	55.6

½Na_2CO_3, 18°

2 000	34.5
3 000	27.00

$NaHCO_2$, 18°

2 000	43.0
3 000	34.7
4 000	28.1

$NaC_2H_3O_2$, 18°

C	$10^6\kappa/C$
2 000	30.0
3 000	22.0
4 000	(15.6)
5 000	10.5

$NaC_2H_5CO_2$, 18°

2 000	24.8
3 000	16.63
4 000	10.89

NaCNS, 18°

2 000	59.7
3 000	50.7
4 000	43.64

½Na_2SiO_3

18°	
2 000	51.1
3 880	28.2
5 880	13.7
25°	
2 000	57.3

½Na_2CrO_4, 18°

2 000	46.6
3 000	37.8
4 000	30.6

KOH, 18°

2 000	160.6
3 000	140.4
4 000	122.0
5 000	105.6
6 000	(90.6)
7 000	77.1
9 292	51.4
10 690	39.3

$KHSO_4$, 18°

2 000	155.5

½K_2S, 18°

2 000	121.4
3 000	108.8
4 000	97.9
5 000	86.8
6 000	74.0
7 000	61.0
9 320	44.1
12 500	20.6

KN_3

0°	
2 000	56.8
3 000	53.3
35°	
2 000	108
3 000	99
4 000	92

⅓KH_2PO_4, 18°

2 000	17.7
3 000	16.3

⅓K_2HPO_4, 0°

1 500	22.3

$\frac{1}{2}K_2CO_3$, 18°	
C	$10^6\kappa/C$
2 000	62.3
3 000	55.2
4 000	48.7
5 000	42.7
6 000	37.5
8 200	26.5
11 160	13.14

$\frac{1}{2}K_2C_2O_4$, 18°	
1 293	70.7

$\frac{1}{2}KHCO_3$, 18°	
1 032	36.0
2 132	32.2

$KC_2H_3O_2$, 18°	
C	$10^6\kappa/C$
2 000	51.3
3 000	41.4
4 000	32.7
5 000	24.8
6 000	18.3
7 500	11.22
9 128	5.24

KCN, 18°	
1 029	99.7

KCNS, 18°	
2 000	86.7

$\frac{1}{3}K_3Fe(CN)_6$, 18°	
C	$10^6\kappa/C$
2 000	75.3

$\frac{1}{4}K_4Fe(CN)_6$, 18°	
2 000	62.5

$\frac{1}{2}K_2CrO_4$, 18°	
2 000	71.9
3 000	59.8

RbOH, 18°	
2 000	168.6
3 000	148.8

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abbott and Bray, *1*, **31**: 729; 09. (2) Agafonov, *53*, **35**: 649; 03. (3) Althammer, *Diss.*, Halle, 1913. (4) Archibald, *292*, **10**: 33; 03. (5) Arrhenius, *7*, **4**: 96; 89. (6) Arrhenius, *7*, **9**: 339; 92. (7) Auerbach and Zeglin, *7*, **103**: 178; 22. (8) Aufrecht, *Diss.*, Berlin, 1904. (9) Bailly, *14*, **6**: 215; 16.

(10) Barth, *7*, **9**: 176; 92. (11) Bencowitz and Renshaw, New York University, *0*. (12) Berkeley, Hartley and Stephenson, *62*, **209**: 331; 09. (13) Berthelot, *6*, **28**: 5; 93. (14) Bhattacharyya and Dhar, *64P*, **18**: 373; 15. (15) Bjerrum, *7*, **59**: 336; 07. (16) Bjerrum, *7*, **59**: 581; 07. (17) Bjerrum, *93*, **118**: 131; 21. (18) Bock, *8*, **30**: 631; 87. (19) Bodländer, *Diss.*, Berlin, 1915.

(20) Böeseken and van Rossem, *70*, **30**: 392; **11**. (21) Bogojiavlenskii, *53*, **44**: 1813; 12. (22) Boltwood, *7*, **22**: 132; 97. (23) Bousfield and Lowry, *62*, **204**: 253; 05. (24) Bray and Hunt, *1*, **33**: 781; 11. (25) Bray and McKay, *1*, **32**: 914; 10. (26) Bray and Winninghoff, *1*, **33**: 1663; 11. (27) Bredig, *7*, **12**: 230; 93. (28) Bredig, *7*, **13**: 191; 94. (29) Briner, Tykociner and Alfimov, *42*, **18**: 3; 20.

(30) Briner and Winkler, *42*, **20**: 201; 23. (31) Brownson and Cray, *4*, **127**: 2923; 25. (32) Bruner, *9*, **19**: 861; 13. (33) Bruni and Levi, *36*, **45 II**: 161; 15. (34) Bruni and Sandonnini, *9*, **16**: 223; 10. (35) Bruns, *96*, **34**: 751; 25. (36) Bruynings Ingenhoes, *Diss.*, Zürich, 1915. (37) Buch, *7*, **70**: 66; 10. (38) Bunbury and Martin, *4*, **105**: 417; 14. (39) Burrows, *4*, **123**: 2026; 23.

(40) Burrows and Turner, *4*, **115**: 1429; 19. (41) Campbell, *4*, **1926**: 3021. (42) Chugaev, *172*, **8 II**: 78; 1909. (43) Chugaev and Chernyaev, *4*, **113**: 884; 18. (44) Chugaev and Khlopin, *93*, **86**: 241; 14. (45) Chugaev and Vladimirov, *34*, **160**: 840; 15. (46) Chugaev and Vladimirov, *53*, **52**: 135; 20. (47) Clausen, *Diss.*, Rostock, 1911. (48) Clausen, *8*, **37**: 51; 12. (49) Clausen, *8*, **44**: 1067; 14.

(50) Cleve, *93*, **32**: 129; 02. (51) Collenberg and Sandved, *93*, **130**: 1; 23. (52) Creighton, *50*, **30**: 1209; 26. (53) Creighton and Ward, *1*, **37**: 2333; 15. (54) Crowe, *69*, **18 III**: 339; 24. (55) Crowe, McGill Univ., *0*. (56) Davis, *292*, **13**: 40; 14. (57) Davis and Jones, *7*, **81**: 68; 12. (58) Dawson and Crann, *4*, **109**: 1262; 16. (59) Dawson and Reiman, *4*, **107**: 1426; 15.

(60) Déguisne, *Diss.*, Strassburg, 1895. (61) Dhar, *93*, **80**: 43; 13. (62) Dittrich, *7*, **29**: 449; 99. (63) Donnan and Harris, *4*, **99**: 1554; 11. (64) Drucker, *9*, **18**: 562; 12. (65) Drucker, *7*, **96**: 381; 20. (66) Drucker, Tarle and Gomez, *9*, **19**: 8; 13. (67) Duff, *4*, **121**: 450; 22. (68) Felipe, *63*, **6**: 422; 05. (69) Flügel, *7*, **79**: 577; 12.

(70) Foster, *2*, **8**: 257; 99. (71) France and Moran, *1*, **46**: 19; 24. (72) Franke, *7*, **16**: 463; 95. (73) Freundlich and Loeb, *205*, **180**: 141; 27. (74) Gibson, *174*, **48**: 117; 13. (75) Gibson and Gibson, *68*, **30**: 254; 09. (76) Goldschmidt, *9*, **19**: 226; 13. (77) Goldschmidt and Larsen, *7*, **71**: 437; 10. (78) Goldschmidt and Weissmann, *9*, **18**: 380; 12. (79) Goodwin and Haskell, *2*, **19**: 369; 04.

(80) Gorke, *7*, **61**: 495; 08. (81) Green, *4*, **93**: 2023; 08. (82) Gropp, *Diss.*, Rostock, 1915. (83) Groschuff, *93*, **47**: 331; 05. (84) Grotrian, *8*, **151**: 378; 74. (85) Grotrian, *8*, **18**: 177; 83. (86) Gupta, *4*, **117**: 67; 20. (87) Harkins, *1*, **33**: 1807; 11. (88) Harkins, Hall and Roberts, *1*, **38**: 2643; 16. (89) Harkins and Paine, *1*, **41**: 1155; 19.

(90) Harkins and Pearce, *1*, **38**: 2679; 16. (91) Harman, *50*, **29**: 1155; 25. (92) Henderson and Kellogg, *1*, **35**: 396; 13. (93) Heydweiller, *8*, **30**: 873; 09. (94) Heydweiller, *Gesammelte Abhandlungen von Fr. Kohlrausch*, II. Leipzig, Barth, 1911. (95) Heydweiller, *8*, **37**: 739; 12. (96) Heydweiller, *93*, **88**: 103; 14. (97) Heydweiller, *8*, **48**: 681; 15. (98) Heydweiller, *93*, **91**: 66; 15. (99) Heydweiller, *93*, **116**: 42; 21.

(100) Hill, *1*, **32**: 1186; 10. (101) Hill and Sirkar, *5*, **83**: 130; 09. (102) van Dorssen, *70*, **29**: 368; 10. (103) Hosking, *3*, **7**: 469; 04. (103.5) Howell, *4*, **1927**: 2843. (104) Hulett, *7*, **42**: 577; 02. (105) Hunt, *1*, **33**: 795; 11. (106) Jaques, *83*, **5**: 225; 09. (107) Jellinek, *7*, **76**: 257; 11. (108) Jellinek and Czerwinski, *7*, **102**: 438; 22. (109) Jones *et al*, *152*, **No. 170**; 12.

(110) Jones *et al*, *152*, **No. 180**; 13. (111) Jones, *4*, **105**: 1547; 14. (112) Jones and Hartmann, *1*, **37**: 240; 15. (113) Jones and Reese, *11*, **20**: 606; 98. (114) Jones and Schumb, *65*, **56**: 199; 21. (115) Kablukov and Sakhanov, *7*, **69**: 419; 09. (116) Kahlenberg, *50*, **5**: 339; 01. (117) Kameyama, *78*, **40**: 131; 21. (118) Kendall, *5*, **85**: 200; 11. (119) Kendall, *4*, **101**: 1275; 12.

(120) Kendall, *3*, **23**: 958; 12. (121) Kendall, *147*, **2**: No. 38; 13. (122) Kendall, *1*, **38**: 1480; 16. (123) Kistiakowsky, *7*, **6**: 97; 90. (124) Klein, *8*, **27**: 151; 86. (124.5) Klemenc and Herzog, *57*, **47**: 405; 27. (125) Kohlrausch, *8*, **159**: 233; 76. (126) Kohlrausch, *8*, **6**: 145; 79. (127) Kohlrausch, *8*, **17**: 69; 82. (128) Kohlrausch, *8*, **26**: 161; 85. (129) Kohlrausch, *76*, **1900**: 1002.

(130) Kohlrausch and Grotrian, *188*, **1874**: 405. (131) Kohlrausch and Grotrian, *8*, **154**: 1; 75. (132) Kohlrausch and Grotrian, *8*, **154**: 215; 75. (133) Kohlrausch and Grüneisen, *76*, **1904**: 1215. (134) Kohlrausch and Henning, *8*, **20**: 96; 06. (135) Kohlrausch and Holborn, *Das Leitvermögen der Elektrolyte*, Leipzig, Teubner, 1916. (136) Kohlrausch, Holborn and Diesselhorst, *8*, **64**: 417; 98. (137) Kohlrausch and Maltby, *76*, **1899**: 665. (138) Kohlrausch and Steinwehr, *76*, **1902**: 581. (139) Koppel and Behrendt, *93*, **35**: 154; 03.

(140) Krannhals, *7*, **5**: 250; 90. (141) Kraus and Parker, *1*, **44**: 2429; 22. (142) Kunz, *7*, **42**: 591; 03. (143) Lamb and Fairhall, *1*, **45**: 378; 23. (144) Lamb and Yngve, *1*, **43**: 2352: 21. (145) Lamble and Lewis, *4*, **107**: 233; 15. (146) Ley, *7*, **30**: 193; 99. (147, 148) Ley and Diekmann, *7*, **106**: 161; 23. (149) Ley and Grau, *7*, **100**: 271; 22.

(150) Linde, *9*, **30**: 255; 24. (151) Lindner, *57*, **33**: 613; 12. (152) Locke, *1*, **46**: 1246; 24. (153) Loeb and Nernst, *7*, **2**: 948; 88. (154) Long, *8*, **11**: 37; 80. (155) Loomis, *8*, **60**: 547; 97. (156) Lorenz and Michael, *93*, **116**: 161; 21. (157) Lorenz and Osswald, *93*, **114**: 209; 20. (158) Lorenz and Posen, *93*, **96**: 81; 16. (159) Lorenz and Scheuermann, *93*, **117**: 121; 21.

(160) Lorenz and Schmidt, *93*, **112**: 209; 20. (160.5) Lottermoser, *9*, **33**: 514; 27. (161) Lovén, *7*, **17**: 374; 95. (162) McBain and Taylor, *25*, **43**: 321; 10. (163) MacGregory, *8*, **51**: 126; 94. (163.5) MacInnes and Shedlovski, The Rockefeller Institute for Medical Research, *0*. (164) Maynard and Howard, *4*, **123**: 960; 23. (165) Mazzetti, *36*, **54**: 891; 24. (166) Melcher, *1*, **32**: 50; 10. (167) Meldrum, *50*, **15**: 474; 11. (168) Menzel, *7*, **105**: 402; 23. (169) Meyer, *93*, **118**: 1; 21.

(170) Meyer, Wassjuchnow, Drapier and Bodländer, *93*, **86**: 257; 14. (171) Miolati and Bellucci, *93*, **26**: 222; 01. (172) Moore and Winmill, *4*, **101**: 1635; 12. (173) Müller, *34*, **155**: 1499; 12. (174) Müller, *27*, **13**: 1057; 13. (175) Müller and Romann, *34*, **156**: 1889; 13. (176) Müller, *27*, **11**: 1001; 12. (176.5) Murata, *41B*, **3**: 47; 28. (177) Muthmann, *25*, **31**: 1829; 98. (177.5) Nagami, *41*, **48**: 501; 27. (178) Naumann, *9*, **16**: 772; 10. (179) Niementowski and Roszkowski, *7*, **22**: 145; 97.

(180) Noyes, *152*, **No. 63**; 07. (181) Noyes, Boggs, Farrell and Stewart, *1*, **33**: 1650; 11. (182) Noyes and Coolidge, *152*, **No. 63**: 9; 07. (183) Noyes and Cooper, *152*, **No. 63**: 115; 07. (184) Noyes and Eastman, *152*, **No. 63**: 239; 07. (185) Noyes and Falk, *1*, **34**: 454; 12. (186) Noyes and Johnston, *1*, **31**: 987; 09. (187) Noyes and Kato, *152*, **No. 63**: 151; 07. (188) Noyes, Kato and Sosman, *7*, **73**: 1; 09. (189) Noyes, Kato and Sosman, *1*, **32**: 159; 10.

(190) Noyes and Lombard, *1*, **33**: 1423; 11. (191) Noyes and Melcher, *152*, **No. 63**: 71; 07. (192) Noyes and Stewart, *1*, **32**: 1133; 10. (193) Ogg, *7*, **27**: 285; 98. (194) Oliveri-Mandalà, *36*, **46 I**: 298; 16. (195) Ostwald, *Lehrbuch der allgemeinen Chemie*. Leipzig, Engelmann, 1891—1903. (196) Ostwald, *221*, **45**: 54; 93. (197) Paine and Evans, *201*, **18**: 1; 14. (198) Parker, *1*, **45**: 2017; 23. (199) Parker and Parker, *1*, **46**: 312; 24.

(200) Patten, Johnson and Mains, *1*, **40**: 1156; 18. (201) Paul, *7*, **110**: 417; 24. (202) Pfanhauser, *9*, **7**: 698; 01. (203) Philip and Courtman, *4*, **97**: 1261; 10. (204) Phillips, *4*, **95**: 59; 09. (205)Pissarzhevskii and Shapovalenko, *53*, **42**: 905: 10. (206) Pope and Read, *4*, **105**: 811; 14. (207) Rabinovich, *7*, **99**: 338; 21. (208) Rabinovich, *7*, **99**: 417; 21. (209) Raikes, Yorke and Ewart, *4*, **1926**: 630.

(210) Ramstedt, *147*, **3**: No. 7; 15. (211) Randall and Scott, *1*, **49**: 636; 27. (212) Randall and Vanselow, *1*, **46**: 2418; 24. (213) Rây, De and Dhar, *4*, **103**: 1562; 13. (214) Rây and Dhar, *4*, **101**: 965; 12. (215) Rây and Dhar, *4*, **103**: 3; 13. (215.5) Rây and Dhar, *4*, **103**: 10; 13. (216) Rây, Dhar and De, *4*, **101**: 1552; 12. (217) Rây and Rakshit, *4*, **101**: 216; 12. (218) Rây and Rakshit, *4*, **103**: 1; 13. (219) Reihlen, *93*, **123**: 173; 22.

(220) Reychler, *28*, **27**: 113; 13. (221) Rimbach and Schubert, *7*, **67**: 183; 09. (222) Rivett, *4*, **1926**: 1063. (223) Robinson and Jones, *4*, **101**: 62; 12. (224) Rördam, *1*, **37**: 557; 15. *61*, **1914**: 243. (225) Romann, *Thesis*, Nancy, 1913. (226) Rosenheim, *93*, **96**: 139; 16. (227) Rosenheim and Dehn, *25*, **48**: 1167; 15. (228) Rosenheim and Leyser, *93*, **119**: 1; 21. (229) Rosenheim and Schwer, *93*, **89**: 224; 14.

(230) Rosenheim, Weinberg and Pinsker, *93*, **84**: 217; 13. (231) Rosenheim and Weinheber, *93*, **69**: 261; 11. (232) Ruby and Kawai, *1*, **48**: 1119; 26. (233) Ruer, *93*, **43**: 282; 05. (234) Ruer and Levin, *93*, **46**: 449; 05. (235) Sakhanov, *9*, **19**: 588; 13. (236) Sandonnini, *9*, **16**: 227; 10. (237) Sand-

qvist, *19*, **6**: No. 9; 16. (238) Schaller, *7*, **25**: 497; 98. (239) Schoch and Felsing, *1*, **38**: 1928; 16.
(240) Senter, *4*, **107**: 908; 15. (241) Sherrill, *1*, **32**: 741; 10. (242) Shibata and Matsuno, *44*, **37**: No. 8; 16. (243) Shilov, *93*, **133**: 55; 24. (244) Sidgwick and Wilsdon, *4*, **99**: 1118; 11. (245) Sloan, *1*, **32**: 946; 10. (246) Smith, *1*, **45**: 360; 23. (247) Smith and Semon, *1*, **46**: 1325; 24. (248) Sosman, *152*, **No. 63**: 193; 07. (248.5) Stoddard, *11*, **47**: 1; 12. (249) Strachan and Chu, *1*, **36**: 810; 14.
(250) Tammann, *7*, **6**: 122; 90. (251) Thiel, *93*, **40**: 280; 04. (252) Tomula, *93*, **118**: 84; 21. (253) Ulpiani and Bernardini, *36*, **42 I**: 390; 12. (254) Van Name and Huff, *12*, **45**: 103; 18. (255) Veley and Manley, *62*, **191**: 365; 98. (256) Venable and Jackson, *1*, **42**: 2531; 20. (257) Vicentini, *24*, **2**: 28, 1699; 84. (258) Wagner, *7*, **28**: 33; 99. (259) Wagner, *7*, **71**: 401; 10.
(260) Walden, *7*, **1**: 529; 87. (261) Walden, *7*, **2**: 49; 88. (262) Walden, *in* Ostwald, *Handbuch der allgemeinen Chemie*, **VI**. Leipzig, Akad. Verlags. m.b.H., 1924. (263) Walden and Ulich, *7*, **106**: 49; 23. (263.5) Walker and Cormack, *4*, **77**: 5; 00. (264) Washburn, *1*, **40**: 122; 18. (265) Washburn and MacInnes, *1*, **33**: 1686; 11. (266) Washburn and Strachan, *1*, **35**: 690; 13. (267) Watkins and Jones, *1*, **37**: 2626; 15. (268) Wedekind and Paschke, *7*, **73**: 118; 10. (269) Weiland, *1*, **40**: 131; 18.
(270) Weinland and Büttner, *93*, **75**: 293; 12. (270.5) Weinland and Ensgraber, *93*, **84**: 340; 14. (271) Weinland and Ensgraber, *93*, **84**: 368; 14. (272) Weinland and Krebs, *93*, **49**: 157; 06. (273) Wershoven, *7*, **5**: 481; 90. (274) Whetham, *5*, **71**: 332; 03. (275) Whetham and Paine, *5*, **81**: 58; 08. (276) White and Jones, *11*, **44**: 159; 10. (277) Wightman and Jones, *11*, **46**: 56; 11. (278) Wightman and Jones, *11*, **48**: 320; 12.

ELECTRICAL CONDUCTIVITY OF SATURATED SOLUTIONS OF SLIGHTLY SOLUBLE ELECTROLYTES

H. I. Schlesinger and Judith E. Wallen

Scope.—Electrolytes with solubilities less than 0.1 equivalent per liter.

Arrangement.—Table 1 gives both the conductance and the solubility computed therefrom. Table 2 gives the conductance only. In each part the arrangement is alphabetical with respect to the symbol of the cation, with organic cations at the end.

Units.—Conductivities in reciprocal ohms (*see* p. 230 for cell constant basis); solubilities in equivalents per liter.

Abbreviations and Symbols.—κ_W = specific conductance of the water used.

κ_S = specific conductance of the solution, corrected for κ_W in the case of salts, uncorrected in all other cases.

S = solubility of the electrolyte as computed from the relation $S = \frac{\kappa'_S \times 10^3}{\alpha \Lambda_0}$, in which Λ_0 is the value assumed for the equivalent conductance of the completely ionized electrolyte, α is the value assumed for the "degree of ionization" (Λ/Λ_0) of the electrolyte in the saturated solution, and κ'_S is the value of κ_S after correction (where possible and necessary) for the effects of hydrolysis. No calculation of S has been attempted in cases where the use of the above relation involves assumptions of doubtful validity. S has been calculated at round values of the temperature, only where the data justified interpolation.

Nature of Crystalline Phase.—Except as otherwise indicated, the crystalline phase was prepared by precipitation methods.

Table 1.—Electrolytes for Which Both Conductance and Solubility Are Given

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Λ_0	α	$S \times 10^6$	Lit.
AgCl	1.55	0.75	0.297				(9)
	4.68	1.21	.393				
	5.00		.404	84.71	1.0	4.77	
	9.66	1.22	.594	97.02	1.0		
	10.00		.611	97.91	1.0	6.24	
	10.9	1.13	.663	100.29	1.0		
	15.00		.879	111.12	1.0	7.91	
	17.33	1.28	1.067	117.27	1.0		
	17.57	1.21	1.085	117.90	1.0		
	18.00	1.16	1.119	119.04	1.0	9.40	
	18	0.56	1.259	119.04	1.0		(12)
	19.95	1.31	1.329				(1)
	20.00		1.261	124.32	1.0	10.01	(9)
	25.00		1.794	137.53	1.0	13.04	
	25.86	1.21	1.899	139.80	.999		
	33.68	2.03	3.007	160.45	.999		

Table 1.—(*Continued*)

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Λ_0	α	$S \times 10^6$	Lit.
AgCl.—(*Cont'd*)	34.26	1.21	3.188	161.98	0.999		(9)
	50.00	≦0.8	7.892	217	.998	36.4	(12)
	100.00	≦0.8	57.840	395.8	.993	146	
	100.00	2.82	56.640	395.8	.993	144	(2)
AgBr	19.96	1.23	0.057	126.36	1.0	0.42	(1)
	21.1	1.21	.075	129.42	1.0	0.545	(9)
	100.0	2.30	7.393	400.04	.999	18	(2)
$AgBrO_3$	19.94	0.93	663.24	105.9	0.954	6 564	(1)
AgI	20.8	1.14	0.002	127.45	1.00	0.013	(9)
$AgIO_3$	9.43	1.05	6.850			97.1	(9)
	10.00		7.031	71.94	0.995	98.3	
	15.00		9.828	81.72	.995	121.0	
	18.00	1.16	11.890	87.58	.995	137.0	
	18.37	1.27	12.160				
	19.95	1.32	14.04				(1)
	20.00		13.55	91.49	.994	149.0	(9)
	25.00		18.20	101.27	.993	181	
	26.60	1.60	20.00				
AgSCN	19.96	1.019	0.096	115.3	1.00	0.78	(1)
	100.0	2.43	13.89				(2)
$BaSO_4$	0.77	0.77	1.125				(9)
	5.00		1.330	85.85	0.995	15.6	
	10.00		1.664	100.14	.995	16.7	
	15.00		2.072	114.43	.995	18.3	
	17.90	1.25	2.389				
	18.00	1.25	2.398	123.0	.994	19.5	
	18.00		2.229	123.0			(12)
	20.00		2.539	128.72	.994	19.8	
	25.00		3.072	143.01	.993	21.6	
	25.00	0.68	2.997	143.01			
	25.00	1.3	2.7	143.01			(4)
	26.75	1.43	3.345				(9)
	50.00	0.8	6.44	229	.99	28.4	(12)
	100.00	.8	13.99	434	.99	32.6	
Barite	3.35	1.40	1.453	81.13			(9)
	5.00		1.576	85.84	.995	18.5	
	10.00		1.978	100.13	.994	19.9	
	15.00		2.440	114.43	.994	21.5	
	17.65	1.40	2.706	122.00			
	18.00	1.40	2.747	123.00	.994	22.4	
	20.00		2.951	128.72	.994	23.1	
	25.00		3.517	143.01	.993	24.8	
	33.27	1.40	4.680	166.64			
$BaC_2O_4.?H_2O$	2.46	2.5	32.09				(9)
	5.00		36.73	80.4	.922	495	
	10.00		47.53	94.2	.917	550	
	15.00		60.39	107.8	.912	614	
	17.38	2.5	68.35				
	18.00	2.5	70.13	116.0	.909	665	
	20.00		74.82	121.5	.907	679	
	25.00		91.62	135.1	.902	752	
	33.73	2.5	127.9				

TABLE 1.—(*Continued*)

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Λ_0	α	$S \times 10^6$	Lit.
$BaC_2O_4.2H_2O$	3.0	1.70	32.97				(9)
	5.00		37.50	80.59	0.922	505	
	5.47	1.70	39.16				
	10.00		50.58	94.21	.915	587	
	11.28	1.70	54.84				
	15.00		67.61	107.8	.905	693	
	17.9	1.70	77.92				
	18.0	1.70	78.32	116.0	.902	749	
	20.00		86.10	121.5	.899	788	
	23.3	1.70	101.0				
	25.00		108.6	135.1	.891	902	
	28.4	1.70	126.3				
$BaC_2O_4.3.5H_2O$	2.07	1.37	33.87				(9)
	4.2	1.37	38.48				
	16.15	1.37	83.79				
	17.85	1.37	94.01				
	18.00	1.37	94.91	116.0	.890	919	
$CaC_2O_4.H_2O$	0.46	1.09	4.296				(9)
	5.00		5.333	77.30	.980	70.3	
	10.00		6.761	90.65	.978	76.15	
	15.00		8.492	103.99	.977	83.4	
	16.4	1.66	8.991				
	18.00	1.86	9.586	112.0	.976	87.3	
	20.00		10.270	117.34	.975	89.5	
	25.00		12.370	130.68	.975	96.9	
	35.8	2.29	17.97				
MgC_2O_4	18.0		199.3	106	.992	2 045	(9)
$PbSO_4$	0.37	2.40	16.467				(9)
	3.48	1.12	19.286				
	5.00		20.40	89.9	.950	230	
	10.00		24.70	104.9	.949	236	
	15.00		29.50	120.0	.948	244	
	16.98	2.07	31.369				
	18.00	2.40	32.60	129.0	.947	249	
	20.00		35.00	135.0	.946	255.5	
	25.00		40.30	150.1	.945	268	
	33.23	4.06	47.899				
TlBr	0.13	1.76	69.13				(9)
	9.37	1.76	107.89				
	10.00		111.3	109.8	.982	1 030	
	15.00		159.1	124.06	.980	1 310	
	18.00		192.0	132.61	.978	1 480	
	20.00		215.8	138.31	.977	1 600	
	20.06	0.75	220.7	138.48			(1)
	25.00		293.8	152.57	.974	1 980	(9)
	25.68	1.76	305.6				
$TlBrO_3$	19.94	1.10	1 079	117.6	.945	9 720	(1)
TlCl	9.54		940.6				(9)
	10.00		966.1	108.04	.945	9 460	
	15.00		1 283	122.10	.942	11 200	
	17.70		1 487.5				
	18.00		1 513	130.54	.939	12 400	
	19.96	0.9	1 678				(1)
	20.00		1 687	136.17	.938	13 200	(9)
	25.00		2 160	150.23	.934	15 400	
	25.76		2 250.8				
TlI	9.90	1.24	11.908				(9)
	10.00		11.99	109.03	.995	111.0	
	15.00		17.68	121.1	.994	147.0	
	18.00	1.24	22.248	131.55	.994	170.0	
	18.08	1.24	22.368				
	20.00		26.12	137.18	.993	191.4	
	20.15		26.154	137.6	.993		(1)
	25.00		36.64	151.26	.992	244.0	(9)
	26.02	1.24	39.391				(9)
$TlIO_3$	19.95	1.06	154.1	103.23	.978	1 530	(1)
TlSCN	19.95	1.0	1 399	127	.944	11 700	(1)
SrC_2O_4	1.35	2.2	24.70				(9)
	5.00		29.38	77.3	.930	408	
	10.00		37.67	90.65	.924	438	
	15.00		47.53	103.99	.922	496	
	15.90	2.2	49.48				
	18.00	2.2	53.95	112.0	.920	523	
	20.00		58.08	117.34	.919	538	
	25.00		70.79	130.68	.914	592	
	31.70	2.2	89.14				
	37.27	2.2	106.1				

TABLE 2.—ELECTROLYTES FOR WHICH THE CONDUCTANCE ONLY IS GIVEN

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Lit.
AgOH	19.96	1.22	29.24	(1)
	24.94	1.15	35.944	
Ag_3PO_4	19.46	1.017	6.100	(1)
AgCN	19.96	0.87	19.0	(1)
Ag_2CrO_4	0.26	1.4	6.664	(9)
	5		8.872	
	10		11.89	
	14.82	1.4	15.594	
	15		15.74	
	17.07	1.4	17.762	
	18.00	1.4	18.581	
	20.00		20.70	
	25.00		26.61	
	30.76	1.4	34.965	
	37.30	1.4	45.954	
	75	(?)	160	
$Ag_2C_2O_4$	9.72	1.06	16.184	(9)
	10.00		16.48	
	15.00		21.68	
	18.00	1.23	25.475	
	18.50	1.47	26.164	
	20.00		28.31	
	25.00		35.97	
	26.90	2.02	39.391	
$AgOOCCH_3$	25.0		4 975	(6)
$AgON.C(CN)CO_2C_2H_5$	25	1.0	234.6	(14)
$AgON:C(CN)CO_2CH(CH_3)_2$	25	1.0	131.8	(14)
$AgCH_3COC(CN)CO_2C_2H_5$	25	1.0	251.5	(14)
Ag *n*-Propionate	25.00	1.0	1 924	(9)
Ag *dl*-Tartrate	25.00	1.0	583.4	(14)
Ag *d*-Tartrate	25.00	1.0	989	(14)
Ag *l*-Tartrate	25.00	1.0	1 009	(14)
Ag *p*-Toluate	25.00	1.0	251.7	(14)
BaF_2	9.50		1 224.4	(9)
	10.00		1 236	
	15.00		1 419	
	17.23		1 500.8	
	18.00		1 528.5	
	20.00		1 607	
	25.00		1 791	
	25.75		1 823.8	
$BaCO_3$	18.00	1.7	25.475	(8)
$BaCrO_4$	0.88	0.75	1.103	(9)
	5.00		1.503	
	10.00		2.056	
	15.00		2.761	
	16.07	1.40	2.910	
	17.42	1.39	3.118	
	18.00	1.82	3.197	
	20.00		3.508	
	25.00		4.345	
	28.08	1.85	4.923	
CaF_2	17.47	1.5	39.370	(9)
	18.00	1.5	39.960	
	26.11	1.5	50.550	
CaF_2(Fluorite)	0.05	1.28	19.580	(9)
	5.00		23.44	
	10.00		28.12	
	15.00		33.81	
	16.08	1.80	34.740	
	17.28	2.10	36.290	
	18.00	2.14	37.060	
	20.00		39.45	
	25.00		45.81	
	26.59	2.57	48.000	
	40.00	3.1	65.530	
$CaSO_4.2H_2O$(Gypsum)	0.51	1.07	1 096.9	(9)
	5.00		1 274.0	
	9.94	1.07	1 486.5	
	10.00		1 490.0	
	14.56	1.07	1 707.3	
	15.00		1 726.0	
	18.00	1.07	1 878.1	
	18.22	1.07	1 889.1	
Large crystals	19.60		1 978	(7)
Fine powder	19.60		2 066	(7)
	19.94	1.1	1 964.0	(9)
	20.00		1 972.0	
	25.00	1.33	2 207.8	

TABLE 2.—(*Continued*)

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Lit.
$CaSO_4.2H_2O$ (Gypsum) Fine powder.—(*Cont'd*)	25.00		2 213.0	(4)
Large crystals	40.00		2 890	(7)
Fine powder	40.00		3 150	(7)
Large crystals	59.95		3 620	(7)
Fine powder	59.95		3 761	(7)
Wyoming	0		944	(5)
	10		1 485	
	18		1 828	
	25		2 204	
	30		2 243	
	35		2 678	
	40		2 842	
	45		3 042	
	55		3 372	
	65.3		3 600	
$CaCO_3$	7.9	1.6	20.27	(8)
	9.38	1.6	21.71	
	10.00		22.03	
	15.00		26.17	
	17.34	1.6	28.25	
	18.00		28.84	
	20.00		30.00	
	25.00		35.97	
	25.96	1.6	36.96	
Calcite	2.03	1.9	15.27	(8)
	5.00		17.07	
	10.00		20.42	
	15.00		24.54	
	17.44	1.9	26.64	
	18.00		27.29	
	20.00		29.17	
	25.00		33.80	
	30.00		38.30	
	32.2	1.9	41.16	
	34.8	1.9	44.06	(8)
Aragonite	3.18	2.2	19.44	
	5.00		20.7	
	10.00		25.1	
	15.00		30.0	
	17.60	2.2	31.72	
	18.00		33.35	
	20.00		35.5	
	25.00		41.0	
	27.9	2.2	43.16	
	30.00		45.4	
	31.1	2.2	46.95	
$CdC_2O_4.3H_2O$	11.13	1.3	19.890	(9)
	15.00		24.95	
	18.00	1.3	26.970	
	18.06	1.3	27.110	
	20.00		30.97	
	25.00		36.22	
	26.75	1.3	38.290	
$Ce(IO_3)_3.2H_2O$	25	1.0	636.8	(13)
$Ce_2(C_2O_4)_3.10H_2O$	25	1.0	0.651	(13)
$Ce_2(C_4H_4O_6)_3.4.5H_2O$	25	1.0	51.66	(13)
CuI	24.62	2.17	2.128	(8)
CuSCN	18	1.2	0.4	(10)
HgCl	0.5	1.12	.60	(9)
	18.0	1.7	1.34	
	24.6	2.2	2.13	
	43.0	2.1	6.1	
HgI_2	18		0.2(?)	(9)
$La(IO_3)_3.3H_2O$	25	1.4	692.0	(13)
$La_2(C_2O_4)_3.10H_2O$	25	1.4	953	(13)
$La_2(C_4H_4O_6)_3.3H_2O$	25	1.4	58.5	(13)
$Li_2PO_3.3.5H_2O$	25	3.2	274	(15)
$Li_3PO_4.0.5H_2O$	25	3.0	937	(15)
$Mg(OH)_2$	Conductance varied with time			(3, 10)
MgF_2	3		139.90	(9)
	18		223.80	
	27		270.70	
$MgCO_3$	8.31		669.5	(8)
	17.78		791.2	
	25.94		885.1	
$Mn(OH)_2$	18	2.0	9.490	(16)
$Nd_2(C_2O_4)_3.10H_2O$	25	1.0	0.764	(13)
$Pb(OH)_2$	19.96	0.97	25.470	(1)
PbF_2	8.99	1.6	330.70	(9)
	10.00		340.4	

TABLE 2.—(*Continued*)

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Lit.
PbF_2.—(*Continued*)	15.00		392.6	(9)
	17.63	1.6	426.20	
	18.00	1.6	430.50	
	20.00		453.9	
	25.00		514.0	
	26.61	1.6	534.50	
$PbCl_2$	19.95		53 540	(1)
$PbBr_2$	19.96		3 692.0	(1)
$Pb(BrO_3)_2$	19.94		4 630.4	(1)
PbI_2	20.10		338.40	(1)
$Pb(IO_3)_2$	9.17	1.13	3.580	(9)
	10.00		3.750	
	15.00		5.012	
	17.1	1.42	5.670	
	18.00	1.25	5.960	
	19.95	0.98	6.500	(1)
	20.00		6.683	(9)
	25.00		8.750	
	25.77	1.77	9.130	
$Pb(SCN)_2$	19.96		5 346	(1)
$Pb_3(PO_4)_2$	19.95	1.207	0.14	(1)
$PbCO_3$	19.96	1.0	1.390	(1)
PbC_2O_4	15.77	1.0	1.174	(9)
	18.00	1.2	1.299	
	19.96	1.2	1.519	(1)
	22.00	1.2	1.54	(9)
$Pr_2(C_2O_4)_3.10H_2O$	25	1.0	1.164	(13)
$Sa_2(C_2O_4)_3$	25	1.0	0.82	(13)
SrF_2	0.26	2.2	101.210	(9)
	5.00		117.5	
	10.00		136.5	
	15.00		157.8	
	17.38	2.2	169.040	
	18.00	2.2	171.83	
	20.00		180.3	
	25.00		204.6	
	27.39	2.2	216.790	
$SrSO_4$	2.85	2.51	84.65	(9)
	5.00		90.78	
	10.00		104.50	
	10.18	2.51	104.80	
	15.00		118.30	
	17.38	2.51	125.09	
	18.00		126.9	
	20.00		132.6	
	25.00		147.40	
	32.26	2.51	170.78	
Celestite	3.27	2.20	85.89	(9)
	5.00		90.78	
	10.00		104.5	
	15.00		118.30	
	17.69	2.19	125.98	
	18.00	2.19	126.87	
	20.00		132.600	
	25.00		147.400	
	32.50	2.19	172.37	
Tl_2S	19.96	0.8	216	(1)
$Tl_2C_2O_4$	19.96		5 341	(1)
$Y_2(C_2O_4)_3.9H_2O$	25	1.0	1.740	(13)
$Yb_2(C_2O_4)_3.10H_2O$	25	1.0	4.849	(13)
$ZnC_2O_4.2H_2O$	9.76	0.98	5.803	(9)
	10.00		5.821	
	15.00		7.112	
	17.92	1.23	7.963	
	18.00	1.20	7.992	
	20.00		8.660	
	25.00		10.210	(9)
	26.15	1.56	10.578	
Antipyrine salicylate	18.0	1.5	1 000	(11)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Böttger, *7*, **46**: 521; 03. (2) Böttger, *7*, **56**: 83; 06. (3) Gjaldbaek, *93*, **144**: 145; 25. (4) Hulett, *7*, **37**: 385; 01. (5) Hulett and Allen, *1*, **24**: 667; 02. (6) Jaques, *83*, **5**: 225; 10. (7) Jones and Partington, *4*, **107**: 1019; 15. (8) Kohlrausch, *7*, **44**: 197; 03. (9) Kohlrausch, *7*, **64**: 129; 08. (10) Kohlrausch and Rose, *7*, **12**: 234; 93. (11) Kolthoff, *70*, **41**: 135; 22. (12) Melcher, *1*, **32**: 50; 10. (13) Rimbach and Schubert, *7*, **67**: 183; 09. (14) Romann, *Thesis*, Nancy, 1913. (15) Rosenheim and Reglin, *93*, **120**: 103; 22. (16) Sackur and Fritzmann, *9*, **15**: 842; 09.

ELECTRICAL CONDUCTIVITY AND IONIZATION CONSTANTS OF WEAK ELECTROLYTES IN AQUEOUS SOLUTION*

JAMES KENDALL

ABBREVIATIONS AND SYMBOLS

Conc. range. The range of concentrations (c) covered by the experimental data.

Λ_c (resp. Λ_0) The equivalent conductance of the electrolyte at the concentration c (resp. zero). The Λ_0 values were obtained by adding to the Λ_0 value for H^+ (resp. OH^-) a Λ_0 value for the anion (resp. cation) of the electrolyte estimated usually from the number of carbon atoms by the Ostwald method.

$$k = \frac{\Lambda_c^2}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

In computing k, the water correction has been applied only in the case of acids weaker than acetic, *v.* (311). Where no constant value is obtained for k, a value for Λ_c is given in its stead.

[ ] Brackets surrounding a value of k indicate that it varies considerably within the concentration range given. Brackets surrounding a Λ value indicate "approximate."

ABRÉVIATIONS ET SYMBOLES

Conc. range. L'intervalle des concentrations (c) couvert par les données expérimentales.

Λ_c (resp. Λ_0) La conductibilité équivalente de l'électrolyte à la concentration c (resp. zéro). Les valeurs de Λ_0 ont été obtenues en ajoutant à la valeur Λ_0 de H^+ (resp. OH^-) la valeur Λ_0 de l'anion (resp. du cation) de l'électrolyte, cette valeur étant généralement calculée par la méthode d' Ostwald à partir du nombre d'atomes de carbone.

$$k = \frac{\Lambda_c^2}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Pour le calcul de k, la correction pour l'eau n'a été faite que dans le cas d'acides plus faibles que l'acétique, *v.* (311). Lorsque la valeur obtenue pour k n'est pas constante, il a été donné à sa place une valeur de Λ_c.

[ ] Des crochets entourant une valeur de k indiquent que celle-ci varie considérablement dans l'intervalle de concentration donné. Des crochets entourant une valeur de Λ indiquent "approximatif."

ABKÜRZUNGEN UND SYMBOLE

Conc. range. Experimentell bestimmter Konzentrations (c) Bereich.

Λ_c (bezw. Λ_0) Die äquivalente Leitfähigkeit bei der Konzentration c des Elektrolyten (bezw. bei der Konzentration Null). Die Werte von Λ_0 sind erhalten durch Addition von Λ_0 für H^+ (bezw. OH^-) zu dem Wert Λ_0 für das Anion (bezw. Kation) des Elektrolyten, welcher Wert gewöhnlich entsprechend der Zahl der Kohlenstoffatome nach der Methode von Ostwald geschätzt ist.

$$k = \frac{\Lambda_c^2}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Bei der Berechnung von k ist die Wasserkorrektur nur bei Säuren die schwächer als Essigsäure sind, angebracht worden, *v.* (311). In dem Falle, wo keine Konstante erhalten wird, steht an dieser Stelle der Wert von Λ_c.

[ ] Ein in Klammern gesetzter Wert von k zeigt an, dass dieser innerhalb des betrachteten Konzentrationsbereiches sich deutlich ändert. Ein in Klammern gesetzter Λ-Wert bedeutet: "ungefähr" dieser Wert.

ABBREVIAZIONI E SIMBOLI

Conc. range. Il campo di concentrazione (c) abbracciato dai dati sperimentali.

Λ_c (risp. Λ_0) La conducibilità equivalente dell'elettrolita alla concentrazione c (risp. zero). I valori di Λ_0 furono ottenuti aggiungendo al valore di Λ_0 per H^+ (risp. OH^-) un valore Λ_0 per l'anione (risp. catione) dell'elettrolita calcolato generalmente dal numero degli atomi di carbonio col metodo di Ostwald.

$$k = \frac{\Lambda_c^2}{\Lambda_0(\Lambda_0 - \Lambda_c)} \quad (1)$$

Nel calcolare k, la correzione per l'acqua è stata applicata solo nel caso degli acidi piu deboli dell'acido acetico, *v.* (311). Se per k non si trova un valore costante viene dato invece un valore per Λ_c.

[ ] Quando un valore di k è compreso fra parentesi significa che esso varia considerevolmente nell'intervallo di concentrazioni indicate. Se un valore di Λ è compreso fra parentesi significa che esso è approssimato.

Λ_0 values for H^+ and OH^-

Temp., °C	H^+	OH^-	Temp., °C	H^+	OH^-
0	229.0	118	25	350.0	196
10	275.6	149	35	399.6	228
15	300.4	164.5	40	421.4	244
18	315.2	174	50	464.3	276

* For more detailed data previous to 1910, *see* Scudder, "The Electrical Conductivity and Ionization Constants of Organic Compounds," New York, Van Nostrand, 1914.

INORGANIC COMPOUNDS

Electrolyte	t, °C	Conc. range, c = formula weight per liter	Λ_0	k(or Λ_c)	Lit.
H_2O	*v.* p. 152				
H_2O_2	25	9.7–6.4	395	$<5 \times 10^{-12}$	(301)
HF	0	1.0–0.001	251	9×10^{-4}	(153)
	25	1.0–0.001	404	6.9×10^{-4}	(5, 153, 266, 432, 454, 480)
	18–40	16.0–0.002			(11, 266); *cf.* (311)
H_2S	18	0.04–0.004	378	5.7×10^{-8}	(589)
				9.1×10^{-8}	(16)
H_2SO_3	25	0.05–0.001	421	1.7×10^{-2}	(39, 295, 316, 432)
H_2Se	25	0.1–0.008	420	1.90×10^{-4}	(108, 271)
H_2Te	18	0.09–0.003	378	2.27×10^{-3}	(108, 271)
H_6TeO_6	25	0.06–0.001	(?)	$\Lambda_{0.03} = 0.98$	(218, 258, 483)
N_2H_4, Hydrazine	25	0.12–0.004	257	2.2×10^{-6}	(104)
HN_3	0	0.05–0.004	266	7×10^{-6}	(429)
				1×10^{-5}	(226)
	5	0.05–0.012	293	8×10^{-6}	(429)
	10	0.05–0.012	322	9×10^{-6}	(429)
	15	0.05–0.012	352	1.1×10^{-5}	(429)
	20	0.05–0.012	382	1.2×10^{-5}	(429)
	25	0.1–0.001	412	1.9×10^{-5}	(226, 606)
HNO	0	0.16–0.007	(?)	$\Lambda_{0.04} = 2.4$	(467); *cf.* (242)
HNO_2	0	0.03–0.001	256	6.0×10^{-4}	(469)
	25	0.002–0.0006	412	4.6×10^{-4}	(512)
H_3NO, Hydroxylamine	18	0.05–0.002	(?)	$\Lambda_{0.05} = 0.4$	(373); *cf.* (485, 622)
NH_4OH	0	0.1–0.04	157	1.39×10^{-5}	(305)
	10	0.06	202	1.63×10^{-5}	(363)
	15	0.1–0.04	225	1.70×10^{-5}	(363)
	18	0.1–0.001	238	1.72×10^{-5}	(305, 362, 421)
	25	0.1–0.04	271	1.81×10^{-5}	(115, 305, 363, 421)
	40	0.1–0.046	342	1.98×10^{-5}	(363)
	50	0.1–0.06	404	1.81×10^{-5}	(363, 421)
	75	0.1	525	1.64×10^{-5}	(421)
	100	0.1–0.01	646	1.35×10^{-5}	(421)
	156	0.1–0.01	907	6.28×10^{-6}	(421)
	218	0.1–0.01	1140	1.80×10^{-6}	(421)
	306	0.1–0.01	1404	9.3×10^{-8}	(421)
	0–50				(46, 104, 206, 251, 321, 326, 433); *cf.* (308)
H_3NO_3S, Aminosulfonic acid	25	0.03–0.001	399	$\Lambda_{0.03} = 315$	(497, 622)
$H_2N_2O_2$, Nitroamine	0	0.5–0.016	(?)	$\Lambda_{0.07} = 0.75$	(40, 242)
$H_3N_3O_6S_3$, Trisulfimide	25	0.015–0.0005	(?)	$\Lambda_{0.015} = 705$	(239)
H_2PO_3	25	0.06–0.0009	(?)	$\Lambda_{0.03} = 200$	(481)
H_3PO_2	25	0.50–0.03	392.5	$\Lambda_{0.06} = 244$	(466)
	18–52	0.5–0.0002			(11, 432)
H_3PO_3	25	0.5–0.0002	(?)	$\Lambda_{0.03} = 243$	(432)
H_3PO_4	18	0.1–0.002	340	$\Lambda_{0.01} = 203$	(421)
	15–156	0.5–0.0002			(11, 199, 326, 421, 432); *cf.* (4, 312, 489)
$H_4P_2O_7$	18	0.05–0.00125	336	$\Lambda_{0.025} = 384$	(4)
H_3AsO_3	25	0.06–0.001	388	2.1×10^{-8}	(627); *cf.* (62, 101)
H_3AsO_4	25	0.12–0.001	386	4.5×10^{-3}	(368, 575, 596)
AgOH	25	0.0006–0.00007	255	9×10^{-5}	(339)
OsO_4	25	0.04	(?)	$\Lambda_{0.04} = 0.15$	(274)
H_3BO_3	18	0.09–0.02	348	$<1.7 \times 10^{-9}$	(589)
		1.8–0.38			(63)

ORGANIC COMPOUNDS

C-Table.—The C-Arrangement; *v.* Vol. III, p. viii

Electrolyte		t, °C	Conc. range, formula weight per liter	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$CHBrN_2O_4$	Dinitrobromomethane	0	0.016–0.004	251	1.7×10^{-4}	(254, 259)
CHN	Hydrocyanic acid	18	0.5–0.06	379	1.32×10^{-9}	(589)
		25	0.25–0.013	(?)	[$\Lambda_{0.03} < 0.5$]	(246, 432, 622)
CHNO	Cyanic acid	0	0.01–0.002	259	1.5×10^{-4}	(417)
CHNS	Thiocyanic acid	25	0.5–0.0002	(?)	$\Lambda_{0.03} = 358$	(372, 432)
CHN_3O_6	Trinitromethane	0	0.016–0.002	251	$\Lambda_{0.016} = 234$	(247); *cf.* (256)
		25	0.03–0.002	395	$\Lambda_{0.016} = 360$	(247); *cf.* (256)
$CH_2N_2O_4$	Dinitromethane	0	0.016–0.002	251	1.5×10^{-4}	(225)
		25	0.016–0.002	392	2.6×10^{-4}	(225)
CH_2N_4	Tetrazole	25	0.03–0.008	400	1.28×10^{-5}	(427)
		0–35	0.03–0.001			(42, 427, 428, 551)
CH_2O	Formaldehyde	25	0.03–0.0016	(?)	$\Lambda_{0.03} = 2.4$	(315)
CH_2O_2	Formic acid	18	0.25–0.001	362	2.0×10^{-4}	(17)
		25	0.12–0.001	404	2.1×10^{-4}	(436)
		10–54.3	1.0–0.0001			(12, 45, 273, 293, 437)
CH_2O_3	Carbonic acid	0	0.04–0.006	254	2.43×10^{-7}	(310)
		18	0.03–0.01	355.7	3.09×10^{-7}	(310)
		25	0.03–0.007	396.6	3.44×10^{-7}	(310)
		0–40	0.4–0.003			(325, 452, 589, 613)
CH_3NO	Formamide	19	0.4–0.06	(?)	$\Lambda_{0.06} = 0.06$	(574)
CH_3NO_2	Formhydroxamic acid	25	0.06–0.016	393	1×10^{-7}	(426)
CH_3NO_2	Nitromethane	25	0.24–0.10	393	1.0×10^{-11}	(232)
$CH_3N_3O_3$	Nitrourea	0	0.03–0.002	251	3.9×10^{-5}	(43)
		10–40	0.03–0.002			(43)
CH_3N_5	5-Amino-1, 2, 3, 4-tetrazole	0	0.05–0.003	251	3.4×10^{-7}	(43)
		10	0.05–0.003	305	4.5×10^{-7}	(43)
		20	0.05–0.003	364	6.2×10^{-7}	(43)
		25	0.06–0.005	394	6.8×10^{-7}	(42, 43)
		30	0.05–0.003	424	8.0×10^{-7}	(43)
		40	0.05–0.003	481	9.9×10^{-7}	(43)
CH_4N_2O	Urea	25	2.0–0.004	(?)	[$\Lambda_{0.03} = 0.07$]	(85, 557)
$CH_4N_2O_2$	Methylnitroamine	0	0.016–0.002	246	2.6×10^{-5}	(226)
		25	0.03–0.002	383	7.0×10^{-5}	(226, 256)
		40	0.016–0.002	466	8.0×10^{-5}	(226)
CH_4N_2S	Thiourea	25	0.03–0.004	(?)	$\Lambda_{0.03} = 0.07$	(557)
CH_4O_4S	Formaldehyde sulfurous acid	25	0.03–0.0016	(?)	$\Lambda_{0.03} = 360$	(315)
CH_4O_4S	Monomethyl sulfate	25	0.03–0.001	(?)	$\Lambda_{0.03} = 368$	(434)
CH_5AsO_3	Methylarsonic acid	0	0.06–0.001	245	4.3×10^{-7}	(628)
		25	0.06–0.001	382	4.1×10^{-7}	(628)
CH_5N	Methylamine	25	0.12–0.002	258	4.0×10^{-4}	(104, 110)
CH_5N_3	Guanidine	25	0.06–0.004	249	$\Lambda_{0.06} = 190$	(433)
CH_5N_5O	Diazoguanidine	25	0.03	(?)	$\Lambda_{0.03} = 21.1$	(253)
$C_2HBrClFO_2$	Chlorobromofluoroacetic acid	25	0.03–0.001	385	$\Lambda_{0.03} = 335$	(548)
$C_2HBr_2ClO_2$	Chlorodibromoacetic acid	25	0.03–0.001	385	$\Lambda_{0.03} = 340$	(548)
$C_2HBr_2FO_2$	Dibromofluoroacetic acid	25	0.03–0.001	387	$\Lambda_{0.03} = 360.5$	(542)
$C_2HBr_3O_2$	Tribromoacetic acid	25.2	0.03–0.004	385	$\Lambda_{0.03} = 343$	(542)
$C_2HClF_2O_2$	Chlorodifluoroacetic acid	25	0.03–0.004	387	$\Lambda_{0.03} = 380$	(549)
$C_2HCl_2FO_2$	Dichlorofluoroacetic acid	24.7	0.03–0.001	385	$\Lambda_{0.03} = 355$	(547)
$C_2HCl_3O_2$	Trichloroacetic acid	0	3.0–0.002	248	$\Lambda_{0.03} = 220$	(163, 625)
		12.5	1.0–0.016	314	$\Lambda_{0.03} = 291$	(221)
		18	0.13–0.004	346	$\Lambda_{0.03} = 320$	(162)
		25	1.0–0.001	387	$\Lambda_{0.03} = 346$	(109, 145, 313, 436, 625)
		0–60	1.0–0.0005			(299, 474, 607, 610)
$C_2H_2Cl_2O_2$	Dichloroacetic acid	0	0.03–0.002	249	$\Lambda_{0.03} = 186$	(625)
		12.5	5.0–0.0008	315	$\Lambda_{0.016} = 259$	(221)
		18	1.0–0.001	347	$\Lambda_{0.02} = 275$	(162, 510)

C-Table.—The C-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_2H_2Cl_2O_2$	Dichloroacetic acid.—(*Cont'd*)....	25	1.0–0.001	388.5	$\Lambda_{0.03} = 273$	(109, 313, 436, 625)
		0–65	0.5–0.0005			(172, 327, 384, 450, 526)
$C_2H_2F_2O_2$	Difluoroacetic acid.....	25	0.03–0.001	389	$\Lambda_{0.03} = 302.5$	(544)
$C_2H_2N_8$	Bistetrazole.....	0	0.03–0.008	(?)	$\Lambda_{0.03} = 126.4$	(427)
		12–31	0.03–0.008			(427)
$C_2H_2O_4$	Oxalic acid.....	25	0.03–0.0005	392	$\Lambda_{0.03} = 285$	(131, 404, 436)
		0–65	1.0–0.00001			(45, 48, 123, 126, 149, 198, 300, 326, 352, 354, 554)
$C_2H_3BrO_2$	Bromoacetic acid.....	18	0.3–0.001	350	1.43×10^{-3}	(162)
		25	0.03–0.001	389	1.35×10^{-3}	(436)
		0	0.03–0.002			(328)
$C_2H_3ClO_2$	Chloroacetic acid.....	14.1	0.05–0.0005	332	1.58×10^{-3}	(273)
		25	0.06–0.001	389	1.52×10^{-3}	(109, 146, 384, 436)
		0–52	1.0–0.002			(11, 118, 153, 328)
$C_2H_3Cl_3O_2$	Chloral hydrate.....	0.65	0.01	(?)	$\Lambda_{0.01} = 0.6$	(167)
$C_2H_3FO_2$	Fluoroacetic acid.....	25	0.03–0.001	390	2.1×10^{-3}	(541)
$C_2H_3IO_2$	Iodoacetic acid.....	25	0.03–0.001	389	7.1×10^{-4}	(579)
C_2H_3N	Acetonitrile.....	0	0.03	(?)	$\Lambda_{0.03} = 0.19$	(209)
$C_2H_3NO_3$	Oxamic acid.....	25	0.03–0.001	388	7.7×10^{-3}	(436)
$C_2H_3NO_3$	Oximinoacetic acid.....	25	0.12–0.001	390	9.7×10^{-4}	(244, 291)
$C_2H_3N_3O_2$	Triazoacetic acid.....	25	0.07–0.003	390	9.4×10^{-4}	(453)
$C_2H_3N_5O$	Tetrazole amide.....	20	0.03–0.008	369	3.3×10^{-3}	(427)
		0–35	0.03–0.008			(427)
C_2H_4BrNO	*N*-Bromoacetamide.....	0	0.03	(?)	[$\Lambda_{0.03} = 0.2$]	(237)
		25	0.06	(?)	[$\Lambda_{0.06} = 0.15$]	(237)
C_2H_4ClNO	*N*-Chloroacetamide.....	25	0.03	(?)	[$\Lambda_{0.03} = 0.5$]	(237)
$C_2H_4F_2N_2O_2$	Difluoroethylnitroamine.....	25	0.03–0.001	386	1.34×10^{-5}	(545)
$C_2H_4F_2O$	Difluoroethyl alcohol.....	25	0.5	(?)	$\Lambda_{0.5} = 0.02$	(543)
$C_2H_4N_2O_2$	Hydraziacetic acid.....	25	0.03	(?)	$\Lambda_{0.03} = 78$	(243)
$C_2H_4N_2O_3$	Ethylnitrolic acid.....	0	0.03	248	5×10^{-9} (?)	(235); *cf.* (209)
$C_2H_4N_2O_4$	Dinitroethane.....	0	0.016–0.004	249	2.2×10^{-6}	(259)
		25	0.03–0.008	392	5.6×10^{-6}	(342)
$C_2H_4N_2O_4$	Oxaldihydroxamic acid.....	25	0.03–0.008	389	1.7×10^{-7}	(426)
C_2H_4O	Acetaldehyde.....	25	0.08–0.001	(?)	$\Lambda_{0.08} = 4.7$	(315)
C_2H_4OS	Thioacetic acid.....	25	0.06–0.001	392	4.60×10^{-4}	(436)
$C_2H_4O_2$	Acetic acid.....	18	0.08–0.001	350.2	1.806×10^{-5}	(383, 421, 619)
		25	0.06–0.0005	390.8	1.813×10^{-5}	(109, 308, 311, 475, 560)
		100	0.08–0.01	772	1.1×10^{-5}	(421)
		156	0.08–0.01	979	5.3×10^{-6}	(421)
		218	0.08–0.01	1163	1.7×10^{-6}	(421)
		306	0.08–0.01	1266	1.4×10^{-7}	(421)
		0–52	5.0–0.0005			(11, 35, 37, 40, 124, 149, 293, 321, 326, 363, 376, 435, 436, 437, 491, 500, 609); *cf.* (595)
$C_2H_4O_2S$	Thioglycolic acid.....	25	0.01–0.0004	387	2.85×10^{-4}	(322); *cf.* (436)
$C_2H_4O_3$	Glycolic acid.....	25	0.25–0.001	390	1.49×10^{-4}	(79, 436)
		17–25	0.12–0.001			(35, 45, 377)
$C_2H_4O_4$	Glyoxylic acid.....	25	0.06–0.001	388	4.6×10^{-4}	(436)
$C_2H_5F_2N$	Difluoroethylamine.....	25	0.03–0.008	245	3.3×10^{-7}	(545)
C_2H_5NO	Acetamide.....	15	0.5–0.016	(?)	$\Lambda_{0.03} = 0.63$	(554)
		25	0.03	(?)	$\Lambda_{0.03} = 0.95$	(553)
$C_2H_5NO_2$	Acethydroxamic acid.....	25	0.07–0.02	390	2.7×10^{-8}	(426)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_2H_5NO_2$	Aminoacetic acid	18	0.1	(?)	$\Lambda_{0.1} = 0.035$	(331); *cf.* (45)
		25	1.0–0.016	(?)	$\Lambda_{0.06} = 0.05$	(85, 197); *cf.* (44, 516)
$C_2H_5NO_2$	Isonitroethane	0	0.02	(?)	$\Lambda_{0.02} = 10.0$	(254)
$C_2H_5N_3O_2$	Biuret	25	0.1	(?)	$\Lambda_{0.1} = 0.35$	(85)
C_2H_6HgO	Mercury ethyl hydroxide	25	0.06–0.004	(?)	$\Lambda_{0.016} = 1.7$	(144); *cf.* (104)
$C_2H_6N_2O$	Nitrosodimethylamine	19	0.067	(?)	$\Lambda_{0.067} = 0.41$	(574)
$C_2H_6N_2O$	*O*-Methylisourea	25	0.03–0.001	240	6.2×10^{-5}	(107)
C_2H_6O	Ethyl alcohol	15, 18	All concns. from pure water to 100% alcohol	(?)	Λ extremely small at all concns.	(160)
$C_2H_6O_2$	Glycol	25	4–0.03	(?)	$\Lambda_{0.5} = 0.003$	(77, 82)
$C_2H_6O_4S$	Acetaldehyde sulfurous acid	25	0.04–0.01	382	$\Lambda_{0.04} = 332$	(315)
$C_2H_6O_4S$	Monoethyl sulfate	25	0.03–0.001	(?)	$\Lambda_{0.03} = 363$	(434)
$C_2H_7AsO_2$	Cacodylic acid	0	0.06–0.001	248	4.1×10^{-7}	(628)
		25	0.12–0.001	381	4.1×10^{-7}	(628)
					6.4×10^{-7}	(296)
C_2H_7N	Dimethylamine	25	0.06–0.001	248.5	5.0×10^{-4}	(110); *cf.* (104)
		0–50	0.06			(251)
C_2H_7N	Ethylamine	25	0.12–0.004	246	4.6×10^{-4}	(104)
$C_2H_7NO_2S$	Ethylsulfonamide	25	0.03–0.001	(?)	$\Lambda_{0.03} = 5.0$	(504)
C_2H_7OTl	Thallium dimethyl hydroxide	25	0.12–0.008	(?)	$\Lambda_{0.12} = 132$	(509)
$C_2H_7O_4P$	Dimethyl phosphate	25	0.125–0.001	386	$\Lambda_{0.03} = 317$	(164)
$C_2H_7O_4P$	Monoethyl phosphate	25	0.125–0.002	386	$\Lambda_{0.125} = 156$	(120)
$C_2H_7O_5P$	Monoglycol phosphate	25	0.125–0.002	386	$\Lambda_{0.125} = 193$	(120)
$C_2H_8N_2$	Ethylenediamine	25	0.06–0.004	242	7.1×10^{-5}	(104)
$C_3HCl_3O_2$	Trichloroacrylic acid	25	0.03–0.004	382	$\Lambda_{0.03} = 272$	(72)
$C_3H_2N_2$	Malononitrile	25	0.016	(?)	$\Lambda_{0.016} = 0.40$	(213)
$C_3H_2N_2O_2S$	Thioparabanic acid	25	0.016–0.001	(?)	$\Lambda_{0.016} = 2.5$	(557)
$C_3H_2N_2O_3$	Parabanic acid	25	0.03	390	7.5×10^{-7}	(624)
$C_3H_2N_2O_3$	Cyanonitrosoacetic acid	25	0.06–0.002	389	1.35×10^{-2}	(244)
$C_3H_3ClO_4$	Chloromalonic acid	25	0.03–0.004	384	3.6×10^{-2}	(577)
$C_3H_3Cl_3O_3$	Trichlorolactic acid	25	0.03–0.001	383	4.5×10^{-3}	(378, 436)
		18	0.025–0.013			(419)
$C_3H_3NO_2$	Cyanoacetic acid	25	0.03–0.0002	389.0	3.65×10^{-3}	(109, 313, 436, 466)
		0–35	1.0–0.0005			(102.1, 109, 313, 466, 610, 611)
$C_3H_3NO_2S$	2, 5-Diketotetrahydrothiazole	0	0.25–0.06	249	7.0×10^{-8}	(305)
		18	0.25–0.06	345	1.49×10^{-7}	(305)
		25	0.25–0.03	387	1.84×10^{-7}	(305)
					2.4×10^{-7}	(436)
$C_3H_3NO_2S$	Thiocyanoacetic acid	25	0.03–0.001	389	2.60×10^{-3}	(436)
$C_3H_3N_3O_2S$	Isonitrosothiohydantoin	25	0.002–0.001	385	5×10^{-8}	(235)
$C_3H_3N_3O_3$	Cyanuric acid	25	0.008–0.001	383	1.8×10^{-7}	(231)
					3.7×10^{-7}	(26)
		0–96.2	0.03–0.0005			(231, 456, 610)
$C_3H_4Br_2O_2$	α, α-Dibromopropionic acid	25	0.03–0.001	381	3.0×10^{-2}	(579)
$C_3H_4Br_2O_2$	α, β-Dibromopropionic acid	25	0.03–0.001	381	6.3×10^{-3}	(579)
$C_3H_4N_2$	Glyoxaline	25	0.06–0.004	247	1.1×10^{-7}	(148)
$C_3H_4N_2O$	*N*-Cyanoacetamide	25	0.04–0.0013	381	1.5×10^{-4}	(26); *cf.* (237)
$C_3H_4N_2O_2$	Hydantoin	25	0.03–0.004	388	6.3×10^{-10}	(557, 624)
$C_3H_4N_2O_4$	Dioximinopropionic acid (labile)	25	0.03–0.002	384	4.1×10^{-3}	(244)
$C_3H_4N_2O_4$	Dioximinopropionic acid (stable)	25	0.03–0.001	384	2.80×10^{-3}	(244)
$C_3H_4N_2O_4$	Oxaluric acid	25	0.03–0.001	387	$\Lambda_{0.015} = 303$	(436)
					$\Lambda_{0.015} = 105$	(557)
$C_3H_4N_4O_2$	*N*-Methyltetrazolecarboxylic acid	20	0.016	(?)	$\Lambda_{0.016} = 208.7$	(429)
		0–40	0.016			(429)
$C_3H_4O_2$	Acrylic acid	18	0.03–0.001	350	5.6×10^{-5}	(407)
		25	0.12–0.001	387	5.5×10^{-5}	(436)
$C_3H_4O_3$	Pyroracemic acid (pyruvic acid)	25	0.14–0.001	386	3.2×10^{-3}	(76, 287); *cf.* (436)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_3H_4O_4$	Malonic acid	0	0.1–0.02	247	1.44×10^{-3}	(591)
		25	0.06–0.001	384	1.60×10^{-3}	(49, 436, 577)
		0–35	0.5–0.0005			(45, 328, 609)
$C_3H_4O_5$	Tartronic acid	25	0.09–0.002	383	1.05×10^{-3}	(436)
					4.9×10^{-3}	(519)
$C_3H_5BrO_2$	α-Bromopropionic acid	25	0.008–0.001	382	1.06×10^{-3}	(579)
		0–35	0.03–0.0005			(610)
$C_3H_5BrO_2$	β-Bromopropionic acid	25	0.03–0.001	382	9.5×10^{-5}	(579)
$C_3H_5ClO_2$	α-Chloropropionic acid	25	0.06–0.001	385	1.6×10^{-3}	(344)
$C_3H_5ClO_2$	β-Chloropropionic acid	25	0.06–0.001	385	8.4×10^{-5}	(344)
$C_3H_5ClO_3$	α-Hydroxy-β-chloropropionic acid	25	0.06–0.001	385	7.5×10^{-4}	(523)
$C_3H_5IO_2$	β-Iodopropionic acid	25	0.06–0.001	385	8.8×10^{-5}	(436)
		0–35	0.12–0.0005			(610)
$C_3H_5NO_2$	Isonitrosoacetone	25	0.05–0.02	386	3×10^{-9}	(362); *cf.* (180, 342)
$C_3H_5NO_2S_2$	Dithiocarbamineglycolic acid	25	0.06–0.001	385	5×10^{-4}	(286)
$C_3H_5NO_3$	Nitroacetone	25	0.03–0.004	385	1.0×10^{-5}	(360); *cf.* (256
$C_3H_5NO_3$	α-Oximinopropionic acid	25	0.06–0.001	385	4.8×10^{-4}	(244, 291)
$C_3H_5NO_3$	β-Oximinopropionic acid	25	0.016–0.001	385	9.8×10^{-5}	(244)
$C_3H_5NO_3S$	Carbaminethioglycolic acid	25	0.12–0.001	386	2.5×10^{-4}	(286, 436)
$C_3H_5NO_3S$	Thiocarbamineglycolic acid	25	0.06–0.001	386	1.12×10^{-3}	(286)
$C_3H_5NO_4$	Aminomalonic acid	25	0.06–0.002	384	7.60×10^{-4}	(370)
$C_3H_5NO_4$	β-Nitropropionic acid	25	0.03–0.002	382	1.55×10^{-4}	(579)
$C_3H_5N_3O_2$	α-Triazopropionic acid	25	0.06–0.003	386	8.7×10^{-4}	(453)
$C_3H_5N_3O_4$	Nitromalonamide	25	0.008–0.002	382	5.8×10^{-4}	(233)
$C_3H_6N_2O$	Ethyleneurea	25	0.03–0.004	(?)	$\Lambda_{0.03} = 0.35$	(557)
$C_3H_6N_2O_2S$	Ethylsulfonecyanamide	25	0.01–0.001	373	$[7 \times 10^{-6}]$	(26)
$C_3H_6N_2O_3$	*anti*-Diazourethane	0	0.016–0.002	246	1.4×10^{-6}	(250)
$C_3H_6N_2O_4$	Malondihydroxyamic acid	25	0.03–0.008	385	6×10^{-8}	(426)
$C_3H_6N_2O_4$	Ethyl nitrocarbamate	0	0.06–0.004	246	3.0×10^{-4}	(43)
		10	0.06–0.004	299	3.5×10^{-4}	(43)
		20	0.06–0.004	355	4.4×10^{-4}	(43, 237)
		25	0.06–0.004	384	5.0×10^{-4}	(43, 237)
		30	0.06–0.004	412	5.2×10^{-4}	(43)
		40	0.06–0.004	465	5.8×10^{-4}	(43)
C_3H_6O	Acetone	25	0.5	(?)	$\Lambda_{0.5} = 0.017$	(581)
$C_3H_6O_2$	Propionic acid	25	0.12–0.001	386	1.32×10^{-5}	(163, 200, 436)
		−1 to 65	1.0–0.0005			(11, 35, 37, 118, 293, 437, 558, 609, 611, 619); *cf.* (308)
$C_3H_6O_3$	Hydracrylic acid	25	0.03–0.001	385	2.95×10^{-5}	(378, 436)
$C_3H_6O_3$	Lactic acid	25	0.20–0.0004	385	1.36×10^{-4}	(76, 376, 436); *cf.* (142)
$C_3H_6O_3$	Methoxyacetic acid	25	0.06–0.001	385	3.29×10^{-4}	(436)
					2.94×10^{-4}	(438)
$C_3H_6O_4$	α, β-Glyceric acid	25	1.0–0.001	384	2.23×10^{-4}	(376, 436)
					2.75×10^{-4}	(88)
$C_3H_7ClO_2$	α-Monochlorohydrin	25	1.0–0.5	(?)	$\Lambda_{0.5} = 0.017$	(65, 77)
C_3H_7N	Allylamine	25	0.12–0.004	241	4.9×10^{-5}	(104)
		0–46	0.06			(251)
C_3H_7NO	Acetoxime	25	0.03–0.004	383	$\Lambda_{0.03} = 0.07$	(557)
$C_3H_7NO_2$	α-Aminopropionic acid	25	0.016–0.001	378	$\Lambda_{0.016} = 0.36$	(200); *cf.* (44, 197, 517)
$C_3H_7NO_2$	Methylaminoacetic acid	25	0.0011	(?)	$\Lambda_{0.0011} = 244$	(200)
$C_3H_7NO_2$	Propionohydroxamic acid	25	0.06–0.03	385	2.7×10^{-8}	(426)
$C_3H_8N_2O$	Ethylisourea	25	0.12–0.004	235	1.05×10^{-4}	(107)
$C_3H_8O_2$	Propane-1, 2-diol	25	0.5	(?)	$\Lambda_{0.5} = 0.009$	(77)
$C_3H_8O_2$	Propane-1, 3-diol	25	1.0–0.03	(?)	$\Lambda_{0.5} = 0.009$	(65, 77)
$C_3H_8O_3$	Glycerol	25	8–0.03	(?)	$\Lambda_{0.5} = 0.007$	(77, 82)
$C_3H_8O_4S$	Monopropyl sulfate	25	0.03–0.001	(?)	$\Lambda_{0.03} = 356$	(434)
C_3H_9N	*n*-Propylamine	25	0.25–0.001	239	3.9×10^{-4}	(104, 433)

C-Table.—The C-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
C_3H_9N	Isopropylamine	25	0.12–0.004	239	4.3×10^{-4}	(104)
C_3H_9N	Trimethylamine	25	0.06–0.001	244.5	6.5×10^{-5}	(110); *cf.* (104)
		0–35	0.03			(251)
$C_3H_9O_6P$	Monoglyceryl phosphate	25	0.125–0.002	383	$\Lambda_{0.125} = 190$	(120)
$C_3H_{10}N_2$	Trimethylenediamine	25	0.06–0.004	234	2.8×10^{-4}	(104, 430)
$C_3H_{10}OS$	Trimethylsulfonium hydroxide	25	0.5–0.004	245	$\Lambda_{0.06} = 222$	(495)
$C_3H_{10}OSn$	Tin trimethyl hydroxide	25	0.06–0.004	231	1.5×10^{-7}	(104)
$C_3H_{10}OTe$	Tellurium trimethyl hydroxide	25	0.06–0.004	236	$\Lambda_{0.06} = 210$	(104)
C_4HN_3	Cyanoform	0	0.03–0.001	(?)	$\Lambda_{0.03} = 230$	(245)
		25	0.03–0.001	393	$\Lambda_{0.03} = 362$	(245)
$C_4H_2Br_2N_2O_3$	Dibromobarbituric acid	25	0.016–0.001	384	8.4×10^{-6}	(557)
$C_4H_2Cl_2N_2O_3$	Dichlorobarbituric acid	25	0.016–0.001	384	1.7×10^{-5}	(557)
$C_4H_2N_2O_4$	Alloxan	25	0.03–0.008	384	2.3×10^{-7}	(624); *cf.* (116, 557)
					5×10^{-9}	(85); *cf.* (116, 557)
$C_4H_2NiO_4S_4$	Nickelodithiooxalic acid	25	0.0014–0.0007	(?)	$\Lambda_{0.0014} = 735$	(477)
$C_4H_2N_4Pt$	Platinocyanic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 752$	(575)
$C_4H_2O_4$	Acetylenedicarboxylic acid	25	0.016–0.0005	(?)	$\Lambda_{0.016} = 497$	(436)
$C_4H_3BrO_4$	Bromomaleic acid	25	0.06–0.0002	381	$\Lambda_{0.06} = 254$	(436)
$C_4H_3N_3O_4$	Nitrouracil	25	0.008–0.001	383	3.19×10^{-6}	(557)
$C_4H_3N_3O_4$	Violuric acid	0	0.03	244	1.4×10^{-5}	(216)
		25	0.03–0.002	382	2.67×10^{-5}	(216, 380)
		35.5	0.03	443	3.26×10^{-5}	(216)
		14.5–54.1	0.03			(216)
$C_4H_3N_3O_5$	Nitrobarbituric acid	25	0.03–0.001	382	$\Lambda_{0.016} = 347$	(276, 557)
$C_4H_4Br_2O_4$	Isodibromosuccinic acid	25	0.015–0.0002	381	$\Lambda_{0.015} = 302$	(524)
$C_4H_4Br_2O_4$	*sym.*-Dibromosuccinic acid	25	0.03–0.0009	381	$\Lambda_{0.03} = 262$	(524, 577)
		0–65	0.03–0.0005			(526)
$C_4H_4Cl_2O_4$	*fum.*-2, 3-Dichlorosuccinic acid	25	0.03–0.001	377	$\Lambda_{0.03} = 253$	(400)
$C_4H_4Cl_2O_4$	*mal.*-2, 3-Dichlorosuccinic acid	25	0.06–0.001	377	$\Lambda_{0.03} = 269$	(400)
$C_4H_4N_2O_3$	Barbituric acid	25	0.03–0.001	384	9.6×10^{-5}	(557)
					10.5×10^{-5}	(624)
$C_4H_4N_2O_3$	Methyl cyanonitrosoacetate	0	0.06–0.016	249	1.4×10^{-5}	(411)
		18	0.06–0.016	352	2.3×10^{-5}	(411)
		25	0.06–0.001	390	2.8×10^{-5}	(410, 411)
		35	0.03–0.016	448	3.1×10^{-5}	(411)
		40	0.016	477	3.3×10^{-5}	(411)
$C_4H_4N_2O_3$	Methyloximino-*syn*-oxazolone	0	0.03–0.012	245	8×10^{-6}	(216, 217)
		25	0.03–0.012	384	3.4×10^{-5}	(216, 217)
		35.5	0.03–0.012	445	5.7×10^{-5}	(216, 217)
$C_4H_4N_2O_3$	Methylparabanic acid	25	0.03–0.001	(?)	[$\Lambda_{0.03} = 2.72$]	(557)
$C_4H_4N_2O_4$	Dialuric acid	25	0.008–0.001	381	6×10^{-5}	(85); *cf.* (557)
$C_4H_4N_2O_6$	α, α-Dioximinosuccinic acid	25	0.06–0.004	381	1.0×10^{-2}	(244)
$C_4H_4N_2O_6$	β, β-Dioximinosuccinic acid	25	0.06–0.001	381	$\Lambda_{0.06} = 238$	(244)
$C_4H_4N_4$	*C*-Methyl cyanoosotriazole	25	0.008	(?)	$\Lambda_{0.008} = 4.00$	(429)
		0–40	0.008			(429)
$C_4H_4O_2$	Tetrolic acid	25	0.03–0.0005	388	2.41×10^{-3}	(436)
$C_4H_4O_2S$	α, β-Thiocrotonic acid	24	0.016–0.001	380	2.2×10^{-4}	(468)
$C_4H_4O_4$	Fumaric acid	25	0.04–0.002	383	9.1×10^{-4}	(86, 436)
		0–65	0.03–0.0005			(45, 328, 525, 609)
$C_4H_4O_4$	Maleic acid	18	0.12–0.0005	343	1.37×10^{-2}	(162)
		25	0.06–0.001	383	1.15×10^{-2}	(436, 476)
		0–65	0.12–0.0005			(45, 84, 86, 328, 525, 609)
$C_4H_4O_5$	Hydroxyfumaric acid	17	0.10–0.0016	340	2.72×10^{-3}	(623)
$C_4H_4O_5$	Hydroxymaleic acid	17	0.10–0.0016	340	2.46×10^{-3}	(623)
$C_4H_4O_6$	Dihydroxyfumaric acid	25	0.016–0.002	383	[7.7×10^{-2}]	(519); *cf.* (87)
$C_4H_4O_6$	Dihydroxymaleic acid	25	0.016–0.008	383	[6.7×10^{-2}]	(519); *cf.* (87, 350)
$C_4H_5BrO_4$	*dl*-Bromosuccinic acid	25	0.03–0.002	382	2.70×10^{-3}	(577)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_4H_5BrO_4$	*dl*-Bromosuccinic acid.—(*Cont'd*).	0–25	0.008–0.0005			(525)
$C_4H_5BrO_4$	*l*-Bromosuccinic acid	25	(?)	382	2.70×10^{-3}	(570)
$C_4H_5ClN_2$	*N*-Methylchloroglyoxaline	25	0.06–0.008	238	1.8×10^{-8}	(148)
$C_4H_5ClO_2$	α-Chlorocrotonic acid	25	0.06–0.001	384	7.0×10^{-4}	(436)
$C_4H_5ClO_2$	β-Chlorocrotonic acid	25	0.06–0.001	384	1.42×10^{-4}	(436)
$C_4H_5ClO_2$	α-Chloroisocrotonic acid	25	0.06–0.001	384	1.55×10^{-3}	(436)
$C_4H_5ClO_2$	β-Chloroisocrotonic acid	25	0.06–0.001	384	9.3×10^{-5}	(436)
$C_4H_5ClO_2$	1-Chlorocyclopropanecarboxylic acid	[25]	(?)	(?)	5.5×10^{-4}	(111)
$C_4H_5ClO_4$	*dl*-Chlorosuccinic acid	25	0.03–0.002	382	2.85×10^{-3}	(577)
$C_4H_5ClO_4$	*d*-Chlorosuccinic acid	25	(?)	382	2.85×10^{-3}	(570)
$C_4H_5ClO_4$	*l*-Chlorosuccinic acid	25	(?)	382	2.85×10^{-3}	(570)
$C_4H_5ClO_5$	Chloromalic acid	25	0.06–0.001	382	4.7×10^{-3}	(523)
$C_4H_5Cl_3O_2$	α, α, β-Trichlorobutyric acid	25	0.37–0.0016	379	$\Lambda_{0.02} = 333$	(145, 312, 313, 436, 466)
		18	0.11–0.0017			(162, 419)
$C_4H_5NO_2$	Methyl cyanoacetate	25	0.03–0.016	(?)	$\Lambda_{0.03} = 0.33$	(213)
$C_4H_5NO_2$	γ-Methylisoxazolone	20	0.004	(?)	$\Lambda_{0.004} = 112.3$	(429)
		0–40				(429)
$C_4H_5NO_2$	Succinimide	25	0.06–0.016	385	$\Lambda_{0.03} = 0.5$	(343, 577)
$C_4H_5NO_5$	α-Oximinosuccinic acid	25	0.03–0.004	383	1.1×10^{-3}	(244)
$C_4H_5N_3O_2$	*N*-Methylosotriazolecarboxylic acid	25	0.008	(?)	$\Lambda_{0.008} = 88.5$	(429)
		0–40				(429)
$C_4H_5N_3O_2$	3-Methyl-4-isonitrosopyrazolone	15	0.005–0.003	325	8.8×10^{-7}	(362)
		25	0.008–0.001	381	1.18×10^{-8}	(362); *cf.* (235)
		40	0.005–0.003	462	1.70×10^{-8}	(362)
$C_4H_5N_3O_3$	4-Methyl-1-hydroxy-1, 2, 5-triazole-3-carboxylic acid	21.5	0.04–0.003	355	6.0×10^{-3}	(175)
$C_4H_6Br_2O_4S$	β-Dibromomethylsulfonepropionic acid	25	0.06–0.004	377	1.97×10^{-4}	(358)
$C_4H_6Cl_2O_2$	*fum.*-α, β-Dichlorobutyric acid	25	0.03–0.001	383	5.9×10^{-3}	(400)
$C_4H_6Cl_2O_2$	*mal.*-α, β-Dichlorobutyric acid	25	0.06–0.004	383	7.9×10^{-3}	(400)
$C_4H_6Cl_2O_4S$	β-Dichloromethylsulfonepropionic acid	25	0.06–0.004	378	1.95×10^{-4}	(358)
$C_4H_6N_2$	*N*-Methylglyoxaline	25	0.06–0.002	245	2.2×10^{-7}	(148)
$C_4H_6N_2$	α-Methylglyoxaline	25	0.06–0.001	245	4.2×10^{-7}	(148)
$C_4H_6N_2$	μ-Methylglyoxaline	25	0.06–0.001	239	1.3×10^{-6}	(148)
$C_4H_6N_2O_2$	Ethyl cyanocarbamate	25	0.02–0.0013	381	4.7×10^{-4}	(26)
$C_4H_6N_2O_2$	Lactocyanamide	25	0.03–0.004	381	$[3 \times 10^{-7}]$	(26)
$C_4H_6N_2O_4$	*amphi*-Dioximinobutyric acid	25	0.008	384	2×10^{-5}	(244)
$C_4H_6N_2O_4$	*syn*-Dioximinobutyric acid	25	0.03–0.004	384	1.3×10^{-2}	(244)
$C_4H_6N_4O_2$	Ethyl tetrazolecarboxylate	20	0.03–0.004	385	4.0×10^{-5}	(428)
		0–30				(428)
$C_4H_6O_2$	α-Crotonic acid	25	0.12–0.001	384	2.00×10^{-5}	(376, 436)
		0–65	0.12–0.0005			(525, 609)
$C_4H_6O_2$	β-Crotonic acid	25	0.12–0.001	384	3.5×10^{-5}	(436)
$C_4H_6O_2$	Diacetyl	25	1–0.002	385	4×10^{-7}	(78)
$C_4H_6O_2$	Trimethylenecarboxylic acid	25	0.07–0.0015	384	1.68×10^{-5}	(99); *cf.* (93)
					1.40×10^{-5}	(141, 487, 635)
$C_4H_6O_2$	Vinylacetic acid	25	0.06–0.001	387	3.75×10^{-5}	(109); *cf.* (193)
					4.6×10^{-5}	(635)
$C_4H_6O_3$	Vinylglycolic acid	25	0.06–0.001	384	4.8×10^{-4}	(520)
$C_4H_6O_4$	Succinic acid	25	0.12–0.0005	382	6.7×10^{-5}	(54, 138)
					6.5×10^{-5}	(86, 376, 436, 476, 565)
					6.3×10^{-5}	(612)
		0–65	0.98–0.0005			(11, 45, 84, 126, 149, 328, 329, 450, 476, 507, 609)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_4H_6O_4$	Isosuccinic acid	25	0.06–0.001	383	8.4×10^{-4}	(436, 577)
$C_4H_6O_4S$	Thiodiglycolic acid	25	0.06–0.001	384	4.8×10^{-4}	(357, 436)
		0–65	0.12–0.0005			(610, 611)
$C_4H_6O_4S$	Thiomalic acid	25	0.03–0.001	384	5.2×10^{-4}	(482)
$C_4H_6O_4S_2$	Dithiodiglycolic acid	25	0.03–0.016	385	6.7×10^{-4}	(436)
$C_4H_6O_4S_3$	Trithiodiacetic acid	25	0.08–0.0013	381	1.03×10^{-3}	(282)
$C_4H_6O_4Se$	Selenodiglycolic acid	25	0.12–0.001	384	4.17×10^{-4}	(358)
$C_4H_6O_5$	Diglycolic acid	25	0.016–0.001	383	1.08×10^{-3}	(79, 436)
$C_4H_6O_5$	*dl*-Malic acid	25	0.016–0.001	382	3.9×10^{-4}	(436, 570)
$C_4H_6O_5$	*l*-Malic acid	25	0.03–0.001	382	3.88×10^{-4}	(378, 436, 570)
		0–35	0.03–0.0005			(45, 525)
$C_4H_6O_6$	*dl*-Tartaric acid	25	0.06–0.001	382	5.9×10^{-4}	(133, 577)
		17–37				(45, 112)
$C_4H_6O_6$	*d*-Tartaric acid	18	0.1–0.0004	346	9.7×10^{-4}	(440)
		25	1.0–0.004	382	9.6×10^{-4}	(73, 211, 375, 436, 577)
		76	0.1–0.008	619	1.03×10^{-3}	(440)
		0–42	1.0–0.05			(45, 50, 113, 121, 123, 298, 326, 351, 463, 472, 496, 527, 555)
$C_4H_6O_6$	*l*-Tartaric acid	25	0.06–0.004	382	9.6×10^{-4}	(133, 436, 577)
		0–65	0.12–0.0005			(112, 610, 611)
$C_4H_6O_6$	*para*-Tartaric acid	25	0.12–0.004	382	9.6×10^{-4}	(73, 211, 436, 577)
		0–65	0.12–0.0005			(45, 50, 112, 299, 525, 609)
$C_4H_6O_6S$	Sulfonediacetic acid	25	0.06–0.001	384	1.26×10^{-2}	(357)
$C_4H_6O_8$	Dihydroxytartaric acid	25	0.06–0.001	381	$[1.2 \times 10^{-2}]$	(519)
$C_4H_7BrO_2$	α-Bromobutyric acid	25	0.008–0.001	381	1.03×10^{-3}	(579)
		0–35	0.03–0.0005			(610)
$C_4H_7BrO_2$	γ-Bromobutyric acid	25	0.03–0.015	383	2.6×10^{-5}	(344)
$C_4H_7ClO_2$	α-Chlorobutyric acid	25	0.06–0.001	383	1.45×10^{-3}	(344)
$C_4H_7ClO_2$	β-Chlorobutyric acid	25	0.06–0.001	383	8.8×10^{-5}	(344)
$C_4H_7ClO_2$	γ-Chlorobutyric acid	25	0.03–0.015	383	$[\Lambda_{0.03} = 12.2]$	(344)
$C_4H_7ClO_3$	α-Chloro-β-hydroxybutyric acid	25	0.025–0.0008	383	2.5×10^{-3}	(523)
$C_4H_7ClO_3$	α-Hydroxy-β-chlorobutyric acid	25	0.06–0.0005	383	8.1×10^{-4}	(523)
$C_4H_7ClO_3$	α-Hydroxy-β-chloroisobutyric acid	25	0.06–0.0005	383	6.2×10^{-4}	(523)
$C_4H_7F_4N$	Tetrafluorodiethylamine	25	0.06	(?)	$\Lambda_{0.06} = 0.12$	(545)
$C_4H_7F_4O_4P$	Tetrafluorodiethyl phosphate	25	0.03–0.001	383	$\Lambda_{0.03} = 347$	(288)
$C_4H_7IO_2$	γ-Iodobutyric acid	25	0.03–0.015	383	2.3×10^{-5}	(344)
$C_4H_7NO_3$	Acetylaminoacetic acid	25	0.06–0.001	381	2.25×10^{-4}	(436)
$C_4H_7NO_3$	α-Oximinobutyric acid	25	0.06–0.001	384	7.0×10^{-4}	(291); *cf.* (244)
$C_4H_7NO_4$	Aminosuccinic acid	25	0.03–0.001	381	$\Lambda_{0.03} = 17.2$	(537, 577, 622); *cf.* (45)
$C_4H_7NO_4$	Diglycolamic acid	25	0.03–0.001	380	$\Lambda_{0.03} = 63.4$	(537)
$C_4H_7NO_4$	*l*-Malamic acid	25	0.03–0.001	383	2.76×10^{-4}	(369)
$C_4H_7NO_4$	Ethyl nitroacetate	25	0.04–0.002	384	1.4×10^{-6}	(342, 498)
$C_4H_8N_2O_3$	Aminosuccinamic acid	25	0.06–0.004	380	$\Lambda_{0.06} = 0.096$	(588); *cf.* (577, 622)
$C_4H_8O_2$	*n*-Butyric acid	25	0.12–0.001	383	1.50×10^{-5}	(53, 163, 200, 376, 436, 619)
		0–65	0.5–0.0001			(11, 35, 37, 273, 328, 437, 525, 558, 609)
$C_4H_8O_2$	Isobutyric acid	25	0.06–0.001	383	1.41×10^{-5}	(141, 200, 436)
					1.55×10^{-5}	(53, 163)
		0–65	1.0–0.0005			(293, 525, 558, 609)
$C_4H_8O_2S$	Ethylthioglycolic acid	25	0.07–0.002	383	1.80×10^{-4}	(465)
$C_4H_8O_3$	Ethoxyacetic acid	25	0.06–0.001	383	2.30×10^{-4}	(436)
$C_4H_8O_3$	α-Hydroxybutyric acid	25	1.0–0.0005	385	6×10^{-5}	(10, 432)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_4H_8O_3$	α-Hydroxybutyric acid.—(*Cont'd*)				1.05×10^{-4}	(67)
$C_4H_8O_3$	β-Hydroxybutyric acid	25	0.48–0.0005	385	3.03×10^{-5}	(525.1); *cf.* (10)
					3.3×10^{-5}	(67)
$C_4H_8O_3$	γ-Hydroxybutyric acid	25	0.013–0.003	385	1.90×10^{-5}	(262)
$C_4H_8O_3$	Hydroxyisobutyric acid	25	0.06–0.001	382	1.03×10^{-4}	(378, 436)
		0–65	0.12–0.0005			(610, 611)
$C_4H_8O_3$	α-Methoxypropionic acid	25	(?)	(?)	3.04×10^{-4}	(438)
$C_4H_8O_3$	β-Methoxypropionic acid	25	(?)	(?)	3.46×10^{-5}	(438)
C_4H_9N	Methylene cyclopropaneamine	25	0.07–0.002	235	3.5×10^{-4}	(141)
$C_4H_9NO_2$	γ-Aminobutyric acid	25	0.03	(?)	$\Lambda_{0.03} = 0.2$	(340)
$C_4H_9NO_2$	Butyrohydroxamic acid	25	0.06–0.03	383	2.3×10^{-8}	(426)
$C_4H_9NO_2$	Dimethylaminoacetic acid	25	(?)	(?)	$[2 \times 10^{-7}]$	(297)
$C_4H_9NO_4$	2, 2-Nitromethylpropane-1, 3-diol	25	1–0.125	(?)	$\Lambda_{1.0} = 0.017$	(68)
$C_4H_9NO_5$	Nitrotricarbinolmethane	25	1.7–0.125	(?)	$\Lambda_{0.5} = 0.026$	(65)
$C_4H_9O_6P$	Erythritolphosphoric acid	25	0.125–0.002	383	$\Lambda_{0.125} = 212$	(120)
$C_4H_{10}N_2$	Diethylenediamine	25	0.03–0.004	233	5.3×10^{-5}	(104)
$C_4H_{10}N_2O_4$	Glycoliminohydrin	25	0.016–0.001	(?)	$\Lambda_{0.016} = 71.5$	(255)
$C_4H_{10}N_2O_5$	Dinitroethane alcoholate	25	0.008–0.001	383	1.7×10^{-4}	(247)
$C_4H_{10}O$	Ethyl ether	25	0.5	(?)	$\Lambda_{0.5} = 0.065$	(581)
$C_4H_{10}O_2$	*n*-Butane-1, 4-diol	25	1.0–0.5	(?)	$\Lambda_{1.0} = 0.022$	(65)
$C_4H_{10}O_3S$	Dimethylthetin	25	0.06–0.004	(?)	$\Lambda_{0.06} = 2.1$	(119)
					$\Lambda_{0.06} = 0.87$	(415)
$C_4H_{10}O_4S$	Monoisobutyl sulfate	25	0.03–0.001	(?)	$\Lambda_{0.03} = 350$	(434)
$C_4H_{11}N$	Diethylamine	25	0.12–0.004	234	1.01×10^{-3}	(104)
$C_4H_{11}N$	Isobutylamine	25	0.25–0.001	235	2.6×10^{-4}	(104); *cf.* (141, 433)
$C_4H_{11}N$	*sec.*-Butylamine	25	0.12–0.004	235	3.6×10^{-4}	(104)
$C_4H_{11}N$	*tert.*-Butylamine	25	0.12–0.004	235	2.8×10^{-4}	(104)
$C_4H_{11}O_4P$	Diethyl phosphate	25	0.125–0.001	383	$\Lambda_{0.03} = 304$	(164, 288)
$C_4H_{11}O_4P$	Monoisobutyl phosphate	25	0.125–0.002	383	$\Lambda_{0.125} = 152$	(120)
$C_4H_{11}OTl$	Thallium diethyl hydroxide	25	0.10–0.003	(?)	$\Lambda_{0.10} = 146$	(509)
$C_4H_{12}INO$	Trimethyliodomethylammonium hydroxide	25	0.06–0.004	235	$\Lambda_{0.06} = 210$	(104)
$C_4H_{12}N_2$	Tetramethylenediamine	25	0.03–0.004	231	4.1×10^{-4}	(104, 430)
$C_4H_{13}AsO$	Tetramethylarsonium hydroxide	25	0.06–0.004	236	$\Lambda_{0.06} = 210$	(104)
$C_4H_{13}NO$	Tetramethylammonium hydroxide	25	0.06–0.004	243	$\Lambda_{0.06} = 219$	(104)
$C_4H_{13}OP$	Tetramethylphosphonium hydroxide	25	0.06–0.004	238	$\Lambda_{0.06} = 214$	(104)
$C_4H_{13}OSb$	Tetramethylstibonium hydroxide	25	0.06–0.004	230	$\Lambda_{0.06} = 177$	(104)
$C_5HBr_3O_3$	Tribromotriketopentamethylene	[25]	0.03–0.001	(?)	$\Lambda_{0.03} = 348$	(224)
$C_5HCl_3O_3$	Trichlorotriketopentamethylene	[25]	0.03–0.001	(?)	$\Lambda_{0.03} = 346$	(224)
$C_5HCl_5O_2$	1, 1, 3, 4, 4-Pentachloropentadienecarboxylic acid	(?)	(?)	(?)	6×10^{-2}	(636)
$C_5H_2O_5$	Croconic acid	25	0.07–0.0003	(?)	$\Lambda_{0.07} = 337$	(127)
$C_5H_3N_3O_6$	Nitrouracilcarboxylic acid	25	0.03–0.001	382	$\Lambda_{0.03} = 339$	(557)
$C_5H_4Br_2O_3$	Acetyldibromoacrylic acid	25	0.01–0.0007	380	6.0×10^{-5}	(7)
$C_5H_4N_2O_4$	Methylalloxan	25	0.03–0.001	(?)	$\Lambda_{0.03} = 9.9$	(557)
$C_5H_4N_4O_3$	Uric acid	18	0.00015	336	2×10^{-6}	(267)
		37	0.0004	437	3.2×10^{-6}	(212)
		0–35	0.0005			(610)
$C_5H_4O_2$	Furfural	25	0.5	(?)	$\Lambda_{0.5} = 0.15$	(581)
$C_5H_4O_2S$	α-Thiophenecarboxylic acid	25	0.04–0.0008	385	3.10×10^{-6}	(26, 436, 566)
$C_5H_4O_2S$	β-Thiophenecarboxylic acid	25	0.02–0.0006	385	7.7×10^{-5}	(358, 566)
$C_5H_4O_3$	Pyromeconic acid	25	0.03	(?)	$\Lambda_{0.03} = 0.57$	(436)
$C_5H_4O_3$	Pyromucic acid	25	0.06–0.001	385	7.01×10^{-6}	(378, 436)
		0–65	0.12–0.0005			(526, 609)
$C_5H_4O_3$	Isopyromucic acid	25	0.04–0.014	385	3×10^{-8}	(122)
$C_5H_5BrN_2O_2$	Methylbromouracil	25	0.002–0.001	382	2.5×10^{-8}	(557)
$C_5H_5BrO_3$	Bromotetric acid	25	0.0015–0.0008	383	1×10^{-5}	(573)
$C_5H_5BrO_4$	Bromocitraconic acid	25	0.01–0.0012	380	1.4×10^{-2}	(7)
$C_5H_5ClN_2O_2$	Methylchlorouracil	25	0.002–0.001	382	3.2×10^{-8}	(557)
C_5H_5N	Pyridine	0	All concns.	(?)	Extremely small	(257)
		25	All concns.	(?)	Extremely small	(257)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_5H_5NO_2$	Pyrrole-2-carboxylic acid	25	0.03–0.0008	385	3.9×10^{-5}	(7); *cf.* (378)
$C_5H_5NO_2S$	4-Methylthiazole-5-carboxylic acid	25	0.008–0.0005	382	3.6×10^{-4}	(49)
$C_5H_5NO_3$	Methyl cyanoformylacetate	25	0.03–0.001	384	$\Lambda_{0.03} = 187$	(90)
$C_5H_5N_3O_4$	Methylnitrouracil	25	0.002–0.001	381	4.2×10^{-7}	(557)
$C_5H_5N_3O_4$	Methyl violurate	25	0.004–0.001	381	1.85×10^{-7}	(240)
$C_5H_6N_2$	α-Aminopyridine	25	0.06–0.03	237	1.4×10^{-7}	(556)
$C_5H_6N_2$	β-Aminopyridine	25	0.12–0.06	237	3.8×10^{-8}	(556)
$C_5H_6N_2$	γ-Aminopyridine	25	0.12–0.008	237	1.33×10^{-5}	(556)
$C_5H_6N_2OS$	Methylthiouracil	25	0.002–0.001	383	4.5×10^{-8}	(557)
$C_5H_6N_2O_2$	Methyluracil	25	0.016–0.001	383	4.6×10^{-9}	(557)
$C_5H_6N_2O_3$	Dimethylparabanic acid	25	0.03–0.008	(?)	$\Lambda_{0.03} = 0.35$	(557)
$C_5H_6N_2O_3$	Ethyl cyanonitrosoacetate	25	0.03–0.001	382	2.25×10^{-5}	(410)
$C_5H_6N_2O_3$	Succincyanamic acid	25	0.016–0.001	379	3.0×10^{-4}	(26)
$C_5H_6N_4O_5$	Uric acid glycol	25	0.004	(?)	$\Lambda_{0.004} = 3.27$	(85)
$C_5H_6O_3$	Tetric acid	25	0.03–0.004	382	8.05×10^{-5}	(569)
$C_5H_6O_4$	Citraconic acid	25	0.10–0.001	381	3.33×10^{-3}	(436, 476)
		0–65	0.03–0.0005			(45, 328, 525, 609)
$C_5H_6O_4$	Glutaconic acid	0	0.04–0.0006	246	1.60×10^{-4}	(562)
		25	0.03–0.0008	383	1.72×10^{-4}	(562, 577)
		45	0.03–0.004			(559)
$C_5H_6O_4$	Itaconic acid	25	0.08–0.0007	381	1.18×10^{-4}	(436, 476)
					1.46×10^{-4}	(524)
		0–65	0.03–0.0005			(45, 525, 609)
$C_5H_6O_4$	Mesaconic acid	25	0.02–0.001	381	7.75×10^{-4}	(436, 577)
		0–65	0.03–0.0005			(45, 328, 525, 609)
$C_5H_6O_4$	Trimethylene-1, 1-dicarboxylic acid	25	0.03–0.002	380	1.95×10^{-2}	(99, 524)
$C_5H_6O_4$	*fum.*-Trimethylene-1, 2-dicarboxylic acid	25	0.01–0.003	380	2.05×10^{-4}	(99)
$C_5H_6O_4$	*mal.*-Trimethylene-1, 2-dicarboxylic acid	25	0.02–0.005	380	4.0×10^{-4}	(99)
$C_5H_6O_4S_3$	Trithiocarbondiglycolic acid	25	0.012–0.0015	378	2.6×10^{-3}	(285)
$C_5H_6O_5$	Acetonedicarboxylic acid	25	0.05–0.0016	379	7.7×10^{-4}	(7)
$C_5H_6O_5S_2$	Dithiocarbondiglycolic acid	25	0.06–0.001	378	1.6×10^{-3}	(285)
$C_5H_6O_6$	Ethenyltricarboxylic acid	25	0.03–0.001	379	3.1×10^{-3}	(578)
$C_5H_7BrO_4$	Bromopyrotartaric acid	25	0.016–0.004	382	4.65×10^{-3}	(577)
$C_5H_7NO_2$	Ethyl cyanoacetate	25	0.004–0.002	(?)	$\Lambda_{0.004} = 0.48$	(573)
$C_5H_7N_3$	α, α'-Diaminopyridine	25	0.06	235	6.4×10^{-8}	(556)
$C_5H_7N_3$	α, γ-Diaminopyridine	25	0.12–0.008	235	1.28×10^{-5}	(556)
$C_5H_7N_3$	β, β'-Diaminopyridine	25	0.12–0.06	235	1.0×10^{-7}	(556)
$C_5H_7N_3O$	Methyliminouracil	25	0.008–0.001	383	3.7×10^{-8}	(557)
$C_5H_7N_3O_3$	*N*-Dimethyl cyanurate	25	0.016	(?)	$\Lambda_{0.016} = 0.26$	(456)
$C_5H_8N_2$	*N*-Ethylglyoxaline	25	0.06–0.001	237	2.5×10^{-7}	(148)
$C_5H_8N_2$	μ-Ethylglyoxaline	25	0.06–0.001	238	1.0×10^{-6}	(148)
$C_5H_8N_2O$	Butyrylcyanamide	25	0.03–0.0009	379	1.10×10^{-4}	(26)
$C_5H_8N_2O_3S$	Thiosuccinuric acid	25	0.016–0.001	379	3.26×10^{-5}	(436)
$C_5H_8N_2O_4$	Succinuric acid	25	0.016–0.001	378	3.05×10^{-5}	(436)
$C_5H_8O_2$	Acetylacetone	25	0.06–0.001	382	4.7×10^{-8}	(508)
					1.4×10^{-6}	(213)
$C_5H_8O_2$	Allylacetic acid	25	0.06–0.001	382	2.12×10^{-5}	(190)
$C_5H_8O_2$	Angelic acid	25	0.03–0.0005	382	4.9×10^{-5}	(436)
$C_5H_8O_2$	β-Dimethylacrylic acid	[25]	(?)	(?)	2×10^{-4}	(448)
					2.2×10^{-4}	(451)
$C_5H_8O_2$	Ethylidinepropionic acid	25	0.06–0.001	382	3.47×10^{-5}	(190)
$C_5H_8O_2$	Propylidineacetic acid	25	0.06–0.001	382	1.51×10^{-5}	(190)
$C_5H_8O_2$	Tetramethylenecarboxylic acid	25	0.07–0.001	380	1.81×10^{-5}	(487, 582, 635)
$C_5H_8O_2$	Tiglic acid	25	0.03–0.001	382	9.4×10^{-6}	(436)
$C_5H_8O_2S$	Tetrahydro-α-thiophenecarboxylic acid	25	0.06–0.002	383	1.11×10^{-4}	(26)
$C_5H_8O_2S_3$	Ethyltrithiocarbonglycolic acid	25	0.01–0.0014	378	8.2×10^{-4}	(285)
$C_5H_8O_3$	Methyl acetoacetate	25	0.016	(?)	$\Lambda_{0.016} = 0.28$	(213)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_5H_8O_3$	Levulinic acid	0	0.03–0.002	254	2.2×10^{-5}	(217)
		25	0.03–0.001	378	2.25×10^{-5}	(217)
					2.50×10^{-5}	(436)
		35.5	0.03–0.002	437	2.25×10^{-5}	(217)
		0–35	0.12–0.0005			(610, 611); *cf.* (61, 256, 378)
$C_5H_8O_3S_2$	Ethyl-$\alpha\Delta$-dithiocarbonglycolic acid	25	0.03–0.002	378	2.12×10^{-3}	(285)
$C_5H_8O_3S_2$	Ethyl-$\beta\Delta$-dithiocarbonglycolic acid	25	0.06–0.001	378	6.49×10^{-4}	(284)
$C_5H_8O_4$	Dimethylmalonic acid	25	0.03–0.001	382	7.5×10^{-4}	(390, 436, 577)
		0–65	0.12–0.0005			(526)
$C_5H_8O_4$	Ethylmalonic acid	25	0.03–0.001	382	1.23×10^{-3}	(436, 577)
		0–65	0.12–0.0005			(526)
$C_5H_8O_4$	Glutaric acid	25	0.06–0.001	380	4.67×10^{-5}	(86, 436, 524, 525.2, 565)
$C_5H_8O_4$	Dimethyl malonate	25	0.016–0.008	(?)	$\Lambda_{0.016} = 0.52$	(213)
$C_5H_8O_4$	Monoethyl malonate	25	0.12–0.004	380	4.50×10^{-4}	(582)
$C_5H_8O_4$	Pyrotartaric acid	25	0.03–0.0005	380	8.5×10^{-5}	(95, 436, 561, 577); *cf.* (476)
		17–65	0.12–0.0005			(45, 48, 525, 609)
$C_5H_8O_4$	Monomethyl succinate	25	0.05–0.0016	378	3.25×10^{-5}	(100, 582)
$C_5H_8O_4S$	Ethyl-β-thiocarbonglycolic acid	25	0.06–0.002	380	4.91×10^{-4}	(286)
$C_5H_8O_4S$	Thioglycolhydracrylic acid	25	0.06–0.001	383	2.5×10^{-4}	(357)
$C_5H_8O_4S$	α-Thiolactylglycolic acid	25	0.06–0.001	383	4.7×10^{-4}	(357)
$C_5H_8O_4S_2$	Methylenebisthioglycolic acid	25	0.06–0.002	381	4.6×10^{-4}	(280)
$C_5H_8O_6$	Monomethyl tartrate	25	0.03–0.001	378	4.5×10^{-4}	(577)
$C_5H_8O_6S$	α, α'-Methylethylsulfonedicarboxylic acid	25	0.06–0.001	382	1.2×10^{-2}	(357)
$C_5H_8O_6S$	β, β'-Methylethylsulfonedicarboxylic acid	25	0.06–0.001	382	5.0×10^{-3}	(357)
$C_5H_8O_7$	*meso*-Trihydroxyglutaric acid	25	0.02–0.01	378	6.6×10^{-4}	(492)
$C_5H_8O_7$	*l*-Trihydroxyglutaric acid	25	0.02–0.01	378	1.30×10^{-3}(?)	(492)
$C_5H_8O_7$	*dl*-Trihydroxyglutaric acid	25	0.02–0.01	378	6.8×10^{-4}	(492)
$C_5H_8O_9$	Leuconic acid	25	0.02–0.0006	(?)	$\Lambda_{0.02} = 51.6$	(127)
$C_5H_9BrO_2$	δ-Bromovaleric acid	25	0.015	381	1.9×10^{-5}	(344)
$C_5H_9ClO_2$	δ-Chlorovaleric acid	25	0.03–0.001	381	2.01×10^{-5}	(344)
$C_5H_9IO_2$	δ-Iodovaleric acid	25	0.015	381	1.7×10^{-5}	(344)
$C_5H_9NO_3$	α-Oximinovaleric acid	25	0.06–0.001	382	6.4×10^{-4}	(244, 291)
$C_5H_9NO_3$	γ-Oximinovaleric acid	25	0.03–0.001	382	2.3×10^{-5}	(244)
$C_5H_9NO_3$	α-Oximinoisovaleric acid	25	0.06–0.004	378	1.14×10^{-3}	(265)
$C_5H_9NO_4$	*d*-Aminoglutaric acid	25	0.03–0.001	378	$\Lambda_{0.03} = 10.3$	(44, 577)
$C_5H_9NO_4$	*dl*-Aminoglutaric acid	25	0.03–0.001	378	$\Lambda_{0.03} = 10.2$	(570, 577)
$C_5H_9NO_4$	Ethyl α-nitropropionate	0	0.03–0.007	246	6.5×10^{-7}	(342, 498)
		25	0.03–0.007	383	4×10^{-7}	(342, 498)
$C_5H_{10}O_2$	Methylethylacetic acid	25	0.12–0.001	381	1.67×10^{-5}	(53, 558, 579)
$C_5H_{10}O_2$	Trimethylacetic acid	25	0.03–0.001	381	9.6×10^{-6}	(458)
$C_5H_{10}O_2$	Valeric acid	25	0.06–0.001	381	1.56×10^{-5}	(53, 163, 200, 436)
		10–40	0.25–0.001			(35, 293)
$C_5H_{10}O_2$	Isovaleric acid	25	0.25–0.001	381	1.68×10^{-5}	(53, 163, 200, 558)
		0–65	0.12–0.0005			(610, 611)
$C_5H_{10}O_3$	α-Ethoxypropionic acid	25	(?)	(?)	2.46×10^{-4}	(438)
$C_5H_{10}O_3$	β-Ethoxypropionic acid	25	(?)	(?)	3.19×10^{-5}	(438)
$C_5H_{10}O_3$	Hydroxytrimethylacetic acid	25	0.03–0.001	380	1.37×10^{-5}	(386)
$C_5H_{10}O_3$	α-Hydroxyvaleric acid	25	0.016–0.002	381	1.30×10^{-4}	(378)
$C_5H_{10}O_3$	γ-Hydroxyvaleric acid	25	0.03–0.0009	381	2.00×10^{-5}	(262)
$C_5H_{10}O_3$	γ-Methoxybutyric acid	25	(?)	(?)	2.11×10^{-5}	(438)
$C_5H_{10}O_3$	α-Methoxyisobutyric acid	25	(?)	(?)	1.24×10^{-4}	(438)
$C_5H_{10}O_3$	*n*-Propoxyacetic acid	25	(?)	(?)	2.21×10^{-4}	(438)
$C_5H_{10}O_3$	Isopropoxyacetic acid	25	(?)	(?)	2.03×10^{-4}	(438)
$C_5H_{10}O_5$	Arabinose	25	0.5	(?)	$\Lambda_{0.5} = 0.25$	(71)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_5H_{10}O_5$	Xylose	25	0.5	(?)	$\Lambda_{0.5} = 0.46$	(71)
$C_5H_{11}N$	Piperidine	25	0.12–0.004	234	1.25×10^{-3}	(104)
		0–50	0.06			(251)
$C_5H_{11}NO_2(+H_2O)$	Trimethylaminoacetic acid (betaine)	25	0.06–0.004	(?)	$\Lambda_{0.06} = 1.75$	(119)
$C_5H_{12}ClN$	Chloroamylamine	0	0.05–0.01	134	3.2×10^{-4}	(202)
$C_5H_{12}O_3S$	Dimethyl-α-propionyl thetin	25	0.06–0.002	(?)	$\Lambda_{0.06} = 4.0$	(119)
$C_5H_{12}O_4$	Pentaerythritol	25	0.5–0.03	(?)	$\Lambda_{0.06} = 1.71$	(82)
$C_5H_{13}N$	Isoamylamine	25	0.25–0.001	232	4.0×10^{-4}	(104); *cf.* (433)
$C_5H_{13}N$	Methyldiethylamine	25	0.12–0.004	234	2.2×10^{-4}	(104)
$C_5H_{13}NO$	Vinyltrimethylammonium hydroxide	25	0.06–0.004	241	$\Lambda_{0.06} = 216$	(433)
$C_5H_{14}N_2$	β-Methyltetramethylenediamine	25	0.016–0.004	228	4.4×10^{-4}	(104)
$C_5H_{14}N_2$	Pentamethylenediamine	25	0.06–0.004	228	6.0×10^{-4}	(104, 430)
$C_6HCl_3O_4.H_2O$	Trichlorotetraketohexamethylene hydrate	25	0.016–0.001	380	$\Lambda_{0.016} = 337$	(224)
$C_6H_2BrCl_3O_3.3H_2O$	Trichlorobromotriketohexamethylene trihydrate	25	0.008–0.002	(?)	$\Lambda_{0.008} = 3.3$	(223)
$C_6H_2Br_2O_4$	Bromoanilic acid	25	0.008–0.0002	(?)	$\Lambda_{0.008} = 215$	(406); *cf.* (196)
$C_6H_2Cl_2O_4$	Chloroanilic acid	25	0.008–0.0001	(?)	$\Lambda_{0.008} = 205$	(406); *cf.* (196, 224)
$C_6H_2Cl_4O_5$	Tetrachlorodiketopentamethylene-hydroxycarboxylic acid	[25]	0.04	(?)	$\Lambda_{0.04} = 415$	(224)
$C_6H_2N_2O_8$	Nitroanilic acid	25	0.03–0.001	(?)	$[\Lambda_{0.03} = 679]$	(224)
$C_6H_2N_4O_6$	Dinitrohydroxyphenylenefurazone	25	0.016–0.002	(?)	$\Lambda_{0.016} = 341$	(455)
$C_6H_2N_4O_6$	1, 2-Dinitroso-3, 5-dinitrobenzene	25	0.0005–0.0002	383	1.07×10^{-4}	(455)
$C_6H_2O_6$	Rhodizonic acid	25	0.12–0.0001	(?)	$\Lambda_{0.016} = 106$	(127)
$C_6H_3Br_3N_2O$	2, 4, 6-Tribromobenzenediazonium hydroxide	0	0.001–0.0005	132	$[1.4 \times 10^{-5}]$	(166); *cf.* (228)
$C_6H_3Cl_2NO_3$	4-Nitro-2, 6-dichlorophenol	25	0.003–0.0007	378	2.0×10^{-4}	(26)
$C_6H_3Cl_3O$	2, 4, 6-Trichlorophenol	25	0.004–0.001	382	$[1 \times 10^{-6}]$	(226); *cf.* (229)
$C_6H_3Cl_3O_5$	Trichlorodiketopentamethylene-hydroxycarboxylic acid	25	0.03–0.001	379	$[6 \times 10^{-2}]$	(224, 378)
$C_6H_3N_3O_7$	2, 4, 6-Trinitrophenol	25	0.05–0.0005	384.5	$\Lambda_{0.016} = 355$	(208, 220.1, 314, 418); *cf.* (26, 132, 332, 434, 489, 505)
		0–90	0.05–0.0005			(162, 208, 299, 324, 525, 563, 564)
$C_6H_3N_3O_8$	2, 4, 6-Trinitroresorcinol	25	0.01–0.0013	379	$\Lambda_{0.01} = 354$	(26)
$C_6H_4Br_2N_2O$	2, 4-Dibromobenzenediazonium hydroxide	0	0.004–0.002	135	1.35×10^{-4}	(166)
$C_6H_4Br_3NO_3S$	4, 5, 6-Tribromoaniline-2-sulfonic acid	25	0.005–0.0006	379	$\Lambda_{0.005} = 366$	(436)
$C_6H_4Br_3NO_3S$	2, 4, 6-Tribromoaniline-3-sulfonic acid	25	0.009–0.001	379	$\Lambda_{0.009} = 352$	(436)
$C_6H_4Br_3NO_3S$	2, 5, 6-Tribromoaniline-3-sulfonic acid	25	0.009–0.001	379	$\Lambda_{0.009} = 360$	(436)
$C_6H_4ClNO_3$	4-Nitro-2-chlorophenol	25	0.003–0.0007	379	1.8×10^{-4}	(26)
$C_6H_4Cl_2O$	2, 4-Dichlorophenol	25	0.016–0.004	380	2×10^{-8}	(226)
$C_6H_4FeN_6$	Ferrocyanic acid	25	0.12–0.00006	(?)	$\Lambda_{0.03} = 875$	(432)
$C_6H_4N_2O_3S$	Diazobenzene-p-sulfonic acid	0	0.016	(?)	$\Lambda_{0.016} = 1.6$	(203)
$C_6H_4N_2O_5$	2, 3-Dinitrophenol	25	0.004–0.001	380	1.3×10^{-5}	(278); *cf.* (26)
$C_6H_4N_2O_5$	2, 4-Dinitrophenol	25	0.004–0.001	380	9.6×10^{-5}	(278); *cf.* (26, 432)
$C_6H_4N_2O_5$	2, 5-Dinitrophenol	25	0.004–0.001	380	6.8×10^{-6}	(278); *cf.* (26)
$C_6H_4N_2O_5$	2, 6-Dinitrophenol	25	0.004–0.001	380	2.6×10^{-4}	(278); *cf.* (26)
$C_6H_4N_2O_5$	3, 4-Dinitrophenol	25	0.004–0.001	380	4.2×10^{-6}	(278); *cf.* (26)
$C_6H_4N_2O_5$	3, 5-Dinitrophenol	25	0.01–0.0025	380	2.0×10^{-7}	(278)
$C_6H_4N_2O_6$	2, 6-Dinitrohydroquinol	25	0.005–0.0006	378	7.0×10^{-5}	(26)
$C_6H_4N_2O_6$	3, 5-Dinitropyrocatechol	25	0.004–0.002	378	$\Lambda_{0.004} = 55.0$	(66)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_4O_2$	Quinone	25	0.03	(?)	$\Lambda_{0.03} = 0.03$	(180)
$C_6H_4O_3S$	α-Thienylglyoxylic acid	25	0.03–0.001	383	7.5×10^{-2}	(244)
$C_6H_4O_4$	Comanic acid	25	0.008–0.002	381	2.7×10^{-2}	(446)
$C_6H_4O_5$	Comenic acid	25	0.004–0.003	381	2×10^{-2}	(446)
$C_6H_5AsCl_2O_4$	Dichlorophenolarsonic acid	25	0.016–0.001	374	5.5×10^{-4}	(356)
$C_6H_5BrN_2O$	p-Bromobenzenediazonium hydroxide	0	0.008–0.001	137	1.48×10^{-4}	(166)
$C_6H_5Br_2NO_3S$	4, 5-Dibromoaniline-2-sulfonic acid	25	0.004–0.0009	379	$\Lambda_{0.004} = 360$	(102, 436)
$C_6H_5Br_2NO_3S$	4, 6-Dibromoaniline-2-sulfonic acid	25	0.009–0.001	379	$\Lambda_{0.009} = 360$	(102, 436)
$C_6H_5Br_2NO_3S$	4, 6-Dibromoaniline-3-sulfonic acid	25	0.014–0.0009	379	$\Lambda_{0.014} = 279$	(436)
$C_6H_5Br_2NO_3S$	2, 6-Dibromoaniline-4-sulfonic acid	25	0.016–0.0005	380	$\Lambda_{0.016} = 352$	(165)
C_6H_5ClO	o-Chlorophenol	25	0.025–0.003	382	$[3.6 \times 10^{-8}]$	(26)
C_6H_5ClO	p-Chlorophenol	25	0.016–0.002	382	$[2 \times 10^{-8}]$	(26)
$C_6H_5Cl_2NO_3S$	Dichloroaniline-3-sulfonic acid	25	0.008–0.0005	379	1.4×10^{-3}	(102, 165)
$C_6H_5Cl_3O_4$	Trichloro-R-pentenedihydroxycarboxylic acid	25	0.016–0.002	378	8.5×10^{-3}	(223, 378)
$C_6H_5NO_2$	p-Nitrosophenol	25	0.008–0.001	381	7×10^{-7}	(557)
					3×10^{-7}	(180)
$C_6H_5NO_2$	Pyridine-2-carboxylic acid	25	0.016–0.001	383	5×10^{-6}	(436)
$C_6H_5NO_2$	Pyridine-3-carboxylic acid	25	0.008–0.001	383	1.34×10^{-5}	(436)
$C_6H_5NO_2$	Pyridine-4-carboxylic acid	25	0.008–0.001	383	1.07×10^{-5}	(436)
$C_6H_5NO_3$	Comanamic acid	25	0.016–0.004	381	2.65×10^{-4}	(446)
$C_6H_5NO_3$	α-Hydroxynicotinic acid	25	0.008–0.001	383	5×10^{-6}	(436)
$C_6H_5NO_3$	o-Nitrophenol	0	0.008–0.001	246	5.6×10^{-8}	(226)
		18	(?)	(?)	5.6×10^{-8}	(173)
		25	0.01–0.0005	382	5.6×10^{-8}	(226); *cf.* (26, 201)
					6.5×10^{-8}	(278); *cf.* (26, 201)
					7.2×10^{-8}	(234); *cf.* (26, 201)
		35	0.008–0.002	437	8.0×10^{-8}	(226)
$C_6H_5NO_3$	m-Nitrophenol	10	0.033–0.016	297	3.3×10^{-9}	(367)
		15	0.033–0.016	325	3.9×10^{-9}	(367)
		25	0.033–0.001	382	5.3×10^{-9}	(367); *cf.* (26, 201, 278)
		40	0.033–0.016	465	7.6×10^{-9}	(367)
		50	0.033–0.016	516	9.4×10^{-9}	(367)
$C_6H_5NO_3$	p-Nitrophenol	0	0.03–0.002	246	4.5×10^{-8}	(226)
		10	0.04–0.008	297	4.5×10^{-8}	(363)
		15	0.04–0.008	325	5.2×10^{-8}	(363)
		18	(?)	(?)	5.8×10^{-8}	(173)
		25	0.03–0.002	382	6.9×10^{-8}	(226, 278, 363); *cf.* (26, 201, 234)
		35	0.03–0.004	437	9×10^{-8}	(226)
		40	0.04–0.008	465	1.02×10^{-7}	(363)
		50	0.04–0.008	516	1.26×10^{-7}	(363)
$C_6H_5NO_3$	2-(α)-Pyrrylglyoxylic acid	25	0.016–0.001	383	$[9.5 \times 10^{-3}]$	(7)
$C_6H_5NO_3S$	Thienyl-*syn*-ketoximecarboxylic acid	25	0.016–0.001	378	4.95×10^{-3}	(244)
$C_6H_5NO_4$	Comenamic acid	25	0.002–0.0005	380	2.4×10^{-4}	(446)
$C_6H_5NO_4$	2-Nitroresorcinol	25	0.003–0.0008	379	1.3×10^{-5}	(26)
$C_6H_5NO_4$	4-Nitroresorcinol	25	0.008–0.001	379	1.1×10^{-5}	(26, 66)
$C_6H_5NO_4S$	2-Methylthiazole-4, 5-dicarboxylic acid	25	0.01–0.0025	382	6.5×10^{-2}	(49)
$C_6H_5NO_5S$	m-Nitrobenzenesulfonic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 348$	(434)
		0–65	0.03–0.0005			(6, 10, 611)
$C_6H_5N_3O_3$	p-Nitrobenzenediazonium hydroxide	0	0.016–0.002	139	$[8 \times 10^{-5}]$	(166)
$C_6H_5N_3O_5$	2-Amino-4, 6-dinitrophenol	25	0.002–0.0005	377	4.8×10^{-5}	(526)
		0–65	0.002–0.0005			(526)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_6AsNO_5$	*o*-Nitrophenylarsonic acid	25	0.016–0.001	373	3.5×10^{-4}	(185, 355)
$C_6H_6AsNO_5$	*m*-Nitrophenylarsonic acid	25	0.016–0.001	373	1.32×10^{-3}	(356)
$C_6H_6AsNO_5$	*p*-Nitrophenylarsonic acid	25	0.016–0.001	374	1.37×10^{-3}	(355)
$C_6H_6AsNO_6$	3-Nitro-4-hydroxyphenylarsonic acid	25	0.016–0.001	373	8.1×10^{-4}	(356)
$C_6H_6BrNO_3S$	2-Bromoaniline-5-sulfonic acid	25	0.014–0.0009	380	1×10^{-2}	(102, 436)
$C_6H_6BrNO_3S$	4-Bromoaniline-2-sulfonic acid	25	0.016–0.001	380	1.6×10^{-2}	(436)
$C_6H_6BrNO_3S$	4-Bromoaniline-3-sulfonic acid	25	0.016–0.001	380	7.1×10^{-4}	(102, 436)
$C_6H_6ClNO_4S$	4-Amino-2-chlorophenolsulfonic acid	25	0.008–0.001	378	8.05×10^{-5}	(165)
$C_6H_6INO_3S$	4-Iodoaniline-2-sulfonic acid	25	0.008–0.001	380	$\Lambda_{0.008} = 289.6$	(102)
$C_6H_6INO_3S$	5-Iodoaniline-2-sulfonic acid	25	0.008–0.001	380	$\Lambda_{0.008} = 309.5$	(102)
$C_6H_6INO_3S$	6-Iodoaniline-2-sulfonic acid	25	0.016–0.001	380	$\Lambda_{0.016} = 340$	(102)
$C_6H_6INO_3S$	4-Iodoaniline-3-sulfonic acid	25	0.016–0.001	380	7.0×10^{-4}	(102)
$C_6H_6INO_3S$	5-Iodoaniline-3-sulfonic acid	25	0.016–0.001	380	2.0×10^{-3}	(102)
$C_6H_6INO_3S$	6-Iodoaniline-3-sulfonic acid	25	0.016–0.008	380	$\Lambda_{0.016} = 242$	(102)
$C_6H_6INO_3S$	2-Iodoaniline-4-sulfonic acid	25	0.03–0.001	380	$\Lambda_{0.03} = 267$	(102)
$C_6H_6INO_3S$	3-Iodoaniline-4-sulfonic acid	25	0.004–0.001	380	$\Lambda_{0.004} = 228$	(102)
$C_6H_6N_2O$	Benzenediazonium hydroxide	0	0.03–0.002	142	$1.21 = 10^{-3}$	(144)
$C_6H_6N_2O_2$	*o*-Quinonedioxime	25	0.002–0.001	380	1.8×10^{-7}	(238)
$C_6H_6N_2O_2$	*p*-Quinonedioxime	25	0.00125	(?)	$\Lambda_{0.00125} = 0.25$	(180)
$C_6H_6N_2O_2$	*o*-Diazophenol	25	0.03–0.016	(?)	$\Lambda_{0.03} = 0.9$	(236)
$C_6H_6N_2O_2$	*p*-Diazophenol	25	0.03–0.016	(?)	$\Lambda_{0.03} = 1.4$	(236)
$C_6H_6N_2O_2$	Phenylnitroamine	1	0.02–0.001	250	1.2×10^{-5}	(171)
		10	0.002–0.001	298	1.5×10^{-5}	(171)
		18	0.02–0.001	340	1.7×10^{-5}	(171)
		25	0.008–0.001	378	2.2×10^{-5}	(227); *cf.* (31)
$C_6H_6N_2O_2$	Phenylnitrosohydroxylamine	0	0.008–0.002	246	4×10^{-6}	(227)
$C_6H_6N_2O_3$	2-Amino-4-nitrophenol	25	0.005–0.0012	379	2.5×10^{-7}	(26)
$C_6H_6N_2O_4$	Dimethylalloxan	25	0.03–0.001	(?)	$\Lambda_{0.03} = 8.0$	(557)
$C_6H_6N_2O_4S$	Benzenesulfonitroamide	0	0.025–0.003	(?)	$\Lambda_{0.025} = 228$	(43)
$C_6H_6N_2O_5S$	3-Nitroaniline-6-sulfonic acid	25	0.016–0.002	381	8×10^{-3}	(165)
$C_6H_6N_4O$	6-Methyl-2, 3-triazo-4-hydroxy-7, *O''*-pyridazine	25	0.004–0.001	379	1.7×10^{-5}	(114)
$C_6H_6N_4O_2$	*N*-Dicyanodisuccinamide	25	0.006–0.0008	376	$[6 \times 10^{-5}]$	(26)
$C_6H_6N_4O_3$	α-Methyluric acid	[25]	0.00027	(?)	$[2 \times 10^{-6}]$	(52)
C_6H_6O	Phenol	18	0.1	340	1.3×10^{-10}	(589)
		25	0.12–0.03	383	1.06×10^{-10}	(311); *cf.* (26, 82, 226)
$C_6H_6O_2$	Hydroquinol	25	0.5–0.06	383	$\Lambda_{0.06} = 0.013$	(82); *cf.* (26)
$C_6H_6O_2$	Pyrocatechol	25	0.12–0.03	383	3.2×10^{-10}	(82, 441); *cf.* (26)
$C_6H_6O_2$	Resorcinol	0	0.12–0.03	247	3×10^{-7}	(82, 226); *cf.* (26)
		25	0.12–0.03	383	6×10^{-7}	(82, 226); *cf.* (26)
		40	0.03–0.008	464	3.5×10^{-6}	(82, 226); *cf.* (26)
$C_6H_6O_2S$	Benzenesulfinic acid	18	0.03–0.002	342	$\Lambda_{0.03} = 222$	(15)
		25	0.03–0.001	382	$\Lambda_{0.03} = 242$	(15)
		30	0.03–0.001	410	$\Lambda_{0.03} = 249$	(15)
$C_6H_6O_3$	1, 2, 4-Trihydroxybenzene	25	0.25	381	$\Lambda_{0.025} = 0.32$	(66)
$C_6H_6O_3$	Phloroglucinol	25	0.12–0.008	381	$\Lambda_{0.06} = 0.06$	(82); *cf.* (26)
$C_6H_6O_3$	Pyrogallol	25	1.0–0.005	381	$\Lambda_{0.06} = 0.056$	(26, 82, 376)
$C_6H_6O_3S$	Benzenesulfonic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 348$	(434)
		0–65	0.12–0.0005			(610, 611)
$C_6H_6O_4$	*sym.*-Methyltrimethenyldicarboxylic acid	25	0.016–0.001	382	5.75×10^{-4}	(183)
$C_6H_6O_4S$	Phenolsulfonic acid	0	0.06–0.0003	(?)	$\Lambda_{0.06} = 173$	(387)
$C_6H_6O_6$	Aconitic acid	25	0.04–0.001	378	1.33×10^{-3}	(577)
					1.54×10^{-3}	(582)
		0–35	0.04–0.0005			(45, 525)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_6O_6$	Trimethylene-1, 1, 2-tricarboxylic acid	25	0.03–0.008	377	8.8×10^{-3}	(578)
$C_6H_6O_6S_2$	Benzene-1, 2-disulfonic acid	25	0.125–0.0005	380	$\Lambda_{0.03} = 341$	(164)
$C_6H_6O_6S_2$	Benzene-1, 3-disulfonic acid	25	0.125–0.002	380	$\Lambda_{0.03} = 359$	(164)
$C_6H_6O_6S_2$	Benzene-1, 4-disulfonic acid	25	0.125–0.001	380	$\Lambda_{0.03} = 361$	(164)
$C_6H_6O_7S_2$	Phenoldisulfonic acid	0	0.06–0.0003	(?)	$\Lambda_{0.06} = 322$	(387)
$C_6H_6O_{10}S_3$	Phenoltrisulfonic acid	0	0.06–0.0003	(?)	$\Lambda_{0.06} = 470$	(387)
$C_6H_7AsN_2O_5$	2-Nitro-4-aminophenylarsonic acid	25	0.004–0.002	372	8.4×10^{-5}	(355)
$C_6H_7AsN_2O_5$	3-Nitro-4-aminophenylarsonic acid	25	0.016–0.001	372	3.2×10^{-4}	(356)
$C_6H_7AsO_3$	Phenylarsonic acid	25	0.016–0.001	375	2.5×10^{-4}	(185, 355)
$C_6H_7AsO_4$	*p*-Hydroxyphenylarsonic acid	25	0.016–0.001	375	1.5×10^{-4}	(355)
$C_6H_7AsO_5$	Resorcinolarsonic acid	25	0.016–0.001	374	6.2×10^{-5}	(356)
$C_6H_7BO_2$	Phenylboric acid	25	0.125	(?)	$\Lambda_{0.125} = 0\ 13$	(538)
C_6H_7N	Aniline	25	0.3–0.002	(?)	$\Lambda_{0.02} = 0.17$	(103); *cf.* (44)
C_6H_7N	*α*-Picoline	25	0.09–0.003	237	$[4 \times 10^{-8}]$	(207)
$C_6H_7NO_2S$	Benzenesulfoneamide	0	0.016	(?)	$\Lambda_{0.016} = 0.17$	(222)
		25	0.03–0.001	(?)	$\Lambda_{0.03} = 0.98$	(504)
$C_6H_7NO_2S$	2, 4-Dimethylthiazole-5-carboxylic acid	25	0.004–0.0005	382	1.15×10^{-4}	(49)
$C_6H_7NO_3$	Methyl cyanoacetoacetate	25	0.016–0.001	382	8.2×10^{-4}	(213)
$C_6H_7NO_3S$	*o*-Anilinesulfonic acid	25	0.016–0.001	382	3.25×10^{-3}	(102, 436)
		0–35	0.03–0.0005			(525)
$C_6H_7NO_3S$	*m*-Anilinesulfonic acid	25	0.016–0.001	382	1.82×10^{-4}	(102, 436)
		0–65	0.03–0.0005			(525, 609)
$C_6H_7NO_3S$	*p*-Anilinesulfonic acid	25	0.03–0.001	382	5.70×10^{-4}	(102, 436)
					6.10×10^{-4}	(622)
		0–65	0.03–0.0005			(525, 608, 609)
$C_6H_7NO_4S$	2-Aminophenol-4-sulfonic acid	25	0.016–0.0005	379	9.25×10^{-5}	(102, 165)
$C_6H_7NO_4S$	4-Aminophenol-2-sulfonic acid	25	0.004–0.001	379	8.15×10^{-6}	(102, 165)
$C_6H_7N_3O_4$	Dimethylvioluric acid	25	0.03–0.002	378	1.55×10^{-5}	(379)
$C_6H_7N_3O_5$	Dimethylnitrobarbituric acid	24.5	0.03–0.001	376	$\Lambda_{0.03} = 334$	(276)
$C_6H_8AsNO_3$	Arsanilic acid	25	0.016–0.001	373	5.7×10^{-5}	(185, 356)
$C_6H_8AsNO_4$	3-Hydroxy-4-aminophenylarsonic acid	25	0.002–0.001	373	7×10^{-5}	(355)
$C_6H_8As_2O_6$	*p*-Phenylenediarsonic acid	25	0.016–0.001	372	2.6×10^{-3}	(356)
$C_6H_8N_2O_3$	Propyl cyanonitrosoacetate	25	0.016–0.001	379	2.28×10^{-5}	(410)
$C_6H_8N_2O_3$	5, 5-Dimethylbarbituric acid	25	0.016	381	7.2×10^{-8}	(624)
$C_6H_8N_2O_3$	5-Ethylbarbituric acid	25	0.016	381	3.8×10^{-5}	(624)
$C_6H_8N_2O_3S$	*o*-Phenylenediamine-3-sulfonic acid	25	0.02–0.0007	378	4.8×10^{-5}	(436)
$C_6H_8O_2$	Dihydroresorcinol	25	0.06–0.001	380	5.5×10^{-6}	(508)
$C_6H_8O_2$	Sorbic acid	25	0.008–0.001	382	1.70×10^{-5}	(436)
$C_6H_8O_3$	Hydroxymethyleneacetylacetone	2.6	0.03–0.004	257	1.7×10^{-5}	(124)
$C_6H_8O_3$	Pentic acid	25	0.03–0.001	380	8.6×10^{-5}	(569)
$C_6H_8O_4$	Allylmalonic acid	25	0.03–0.001	382	1.51×10^{-3}	(577)
		0–65	0.12–0.0005			(526)
$C_6H_8O_4$	$\Delta\alpha, \beta$-Dihydromuconic acid	25	0.015–0.0001	380	$[2 \times 10^{-4}]$	(524)
$C_6H_8O_4$	$\Delta\beta, \gamma$-Dihydromuconic acid	25	0.016–0.001	380	1.00×10^{-4}	(524); *cf.* (493)
$C_6H_8O_4$	Dimethylmaleic acid	25	0.016–0.001	380	1.1×10^{-4}	(577)
$C_6H_8O_4$	Ethylfumaric acid	25	0.03–0.001	380	9.2×10^{-4}	(569, 577)
$C_6H_8O_4$	Ethylmaleic acid	25	0.03–0.001	380	2.31×10^{-3}	(577)
$C_6H_8O_4$	Tetramethylene-1, 1-dicarboxylic acid	25	0.06–0.001	380	8.17×10^{-4}	(582); *cf.* (524, 534)
$C_6H_8O_4$	Monoethyl fumarate	25	0.05–0.0014	378	4.73×10^{-4}	(582)
$C_6H_8O_4$	Monoethyl maleate	25	0.02–0.0012	378	1.1×10^{-3}	(582)
$C_6H_8O_4$	*α*-Monomethyl mesaconate	25	0.03–0.001	381	3.49×10^{-4}	(9)
$C_6H_8O_4$	*β*-Monomethyl mesaconate	25	0.03–0.001	379	5.05×10^{-4}	(9)
$C_6H_8O_4$	*α*-Methyleneglutaric acid	25	0.06–0.001	380	6.7×10^{-5}	(186)
$C_6H_8O_4$	*cis*-*β*-Methylglutaconic acid	25	0.06–0.001	379	1.28×10^{-4}	(192)
$C_6H_8O_4$	*trans*-*β*-Methylglutaconic acid	25	0.06–0.001	379	1.38×10^{-4}	(192)
$C_6H_8O_4$	Methylitaconic acid	25	0.03–0.001	380	9.3×10^{-4}	(55, 170, 577)
$C_6H_8O_4$	*cis*-Tetramethylene-1, 2-dicarboxylic acid	25	(?)	380	6.6×10^{-5}	(447)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_8O_4$	*trans*-Tetramethylene-1, 2-dicarboxylic acid	25	(?)	380	2.8×10^{-5}	(447)
$C_6H_8O_6$	*l*-Acetylmalic acid	25	0.06–0.001	378	2.35×10^{-3}	(283)
$C_6H_8O_6$	Propenyltricarboxylic acid	25	0.03–0.001	378	2.99×10^{-3}	(578)
$C_6H_8O_6$	Tricarballylic acid	25	0.06–0.001	378	2.15×10^{-4}	(24, 98, 578, 582)
		0–65	0.12–0.0005			(45, 610, 611)
$C_6H_8O_7$	Citric acid	25	0.06–0.001	378	8.0×10^{-4}	(578, 582)
		0–65	0.12–0.0005			(45, 159, 198, 211, 353, 395, 472, 525, 609)
$C_6H_8O_7$	*d*-Saccharolactonic acid	25.1	0.12–0.001	380	1.3×10^{-3}	(398)
$C_6H_9AsN_2O_3$	*o*-Phenylenediaminearsonic acid	25	0.016–0.001	372	2.3×10^{-5}	(356)
$C_6H_9BrO_4$	α-Ethylbromosuccinic acid	25	0.03–0.002	381	4.1×10^{-3}	(577)
$C_6H_9BrO_4$	β-Ethylbromosuccinic acid	25	0.03–0.002	381	5.2×10^{-3}	(577)
C_6H_9NO	Methylpyridinium hydroxide	25	0.03–0.004	(?)	$\Lambda_{0.03} = 213$	(241)
$C_6H_9NO_4$	Ethyl isonitrosoacetoacetate	0	0.06–0.016	247	4.1×10^{-8}	(411)
		18	0.06–0.016	350	7.3×10^{-8}	(411)
		25	0.06–0.016	388	8.7×10^{-8}	(411, 498)
		35	0.06–0.016	447	1.1×10^{-7}	(411)
		40	0.06–0.016	476	1.2×10^{-7}	(411)
$C_6H_9NO_5$	Monoethyl α-oximinosuccinate	25	0.03–0.001	380	1.88×10^{-4}	(244)
$C_6H_9NO_5$	Monoethyl β-oximinosuccinate	25	0.03–0.008	380	5.2×10^{-3}	(244)
$C_6H_9N_3O_2$	Histidine	25	0.03–0.001	(?)	$\Lambda_{0.03} = 3.7$	(304)
$C_6H_9N_3O_2$	*C*-Methyl-*N*-ethylosotriazolecarboxylic acid	20	0.004	(?)	$\Lambda_{0.004} = 77.9$	(429)
		0–40	0.004			(429)
$C_6H_{10}N_2O$	Isovalerylcyanamide	25	0.02–0.0007	376	1.36×10^{-4}	(26)
$C_6H_{10}N_2O_6$	β, β-Dinitrocaproic acid	25	0.008–0.0005	376	6.84×10^{-4}	(436)
$C_6H_{10}O_2$	Divinylglycol	25	0.75–0.5	(?)	$\Lambda_{0.5} = 0.024$	(65)
$C_6H_{10}O_2$	α, β-Hexenic acid	25	0.06–0.001	380	1.88×10^{-5}	(190)
$C_6H_{10}O_2$	β, γ-Hexenic acid	25	0.06–0.001	380	2.63×10^{-5}	(190); *cf.* (436)
$C_6H_{10}O_2$	γ, δ-Hexenic acid	25	0.06–0.001	380	1.73×10^{-5}	(190)
$C_6H_{10}O_2$	δ, ϵ-Hexenic acid	25	0.06–0.001	380	1.90×10^{-5}	(190)
$C_6H_{10}O_2$	α-Methyl-α, β-pentenic acid	25	0.06–0.008	380	1.05×10^{-5}	(190, 436)
$C_6H_{10}O_2$	α-Methyl-β, γ-pentenic acid	25	0.06–0.001	380	2.99×10^{-5}	(190)
$C_6H_{10}O_2$	α-Methyl-γ, δ-pentenic acid	25	0.06–0.001	380	2.15×10^{-5}	(190)
$C_6H_{10}O_2$	β-Methyl-α, β-pentenic acid	25	0.03–0.001	380	7.5×10^{-6}	(187)
$C_6H_{10}O_2$	β-Methyl-β, γ-pentenic acid	25	0.06–0.001	380	3.0×10^{-5}	(187)
$C_6H_{10}O_2$	Pentamethylenecarboxylic acid	25	0.05–0.0012	378	1.20×10^{-5}	(525.2, 635)
$C_6H_{10}O_2$	Trimethylacrylic acid	25	0.009–0.0005	379	3.8×10^{-5}	(550)
$C_6H_{10}O_3$	Ethyl acetoacetate	1	0.06–0.001	247	1.6×10^{-8}	(431)
		25	0.06–0.001	383	4.4×10^{-8}	(431); *cf.* (213, 569)
		35	0.06–0.001	441	5.3×10^{-8}	(431)
$C_6H_{10}O_3$	γ-Acetobutyric acid	25	0.06–0.0005	379	2.16×10^{-5}	(508)
$C_6H_{10}O_3$	β-Acetoisobutyric acid	25	(?)	(?)	3.03×10^{-5}	(61)
$C_6H_{10}O_3$	Trimethylpyruvic acid	25	1.0–0.016	378	3.4×10^{-2}	(83)
$C_6H_{10}O_4$	Adipic acid	25	0.03–0.001	378	3.63×10^{-5}	(138, 436, 524, 565)
					3.25×10^{-5}	(86)
$C_6H_{10}O_4$	*asym.*-Dimethylsuccinic acid	25	0.03–0.0005	379	7.8×10^{-5}	(20, 49, 95, 451, 577)
					8.2×10^{-5}	(561)
$C_6H_{10}O_4$	*sym.-anti*-Dimethylsuccinic acid	25	0.03–0.001	379	1.36×10^{-4}	(139)
					1.20×10^{-4}	(95, 577, 631)
					1.28×10^{-4}	(84); *cf.* (561)
$C_6H_{10}O_4$	*sym.-p*-Dimethylsuccinic acid	25	0.03–0.0006	379	2.04×10^{-4}	(49, 139); *cf.* (561)
					1.87×10^{-4}	(84, 95, 451, 577, 631)
$C_6H_{10}O_4$	Ethylsuccinic acid	25	0.03–0.001	379	8.3×10^{-5}	(49, 577)
$C_6H_{10}O_4$	Methylethylmalonic acid	25	0.09–0.0007	380	1.61×10^{-3}	(49, 577)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_{10}O_4$	Methylethylmalonic acid.—(*Cont'd*)	0–65	0.12–0.0005			(526)
$C_6H_{10}O_4$	α-Methylglutaric acid	25	0.03–0.001	378	5.2×10^{-5}	(49, 391, 577)
$C_6H_{10}O_4$	β-Methylglutaric acid	25	0.03–0.001	378	5.9×10^{-5}	(525.2, 577)
$C_6H_{10}O_4$	Propylmalonic acid	25	0.06–0.001	382	1.09×10^{-3}	(49, 390, 577)
$C_6H_{10}O_4$	Isopropylmalonic acid	25	0.07–0.001	382	1.24×10^{-3}	(49, 390, 577)
		0–65	0.03–0.0005			(526)
$C_6H_{10}O_4$	Monomethyl pyrotartaric acid	25	0.05–0.006	377	3.85×10^{-5}	(100)
$C_6H_{10}O_4$	Monoethyl succinate	25	0.05–0.002	376	3.01×10^{-5}	(582)
$C_6H_{10}O_4$	Monoethyl isosuccinate	25	0.06–0.002	376	3.85×10^{-4}	(582)
$C_6H_{10}O_4S$	α-Thiodilactylic acid (α-modification)	25	0.06–0.001	382	4.9×10^{-4}	(357)
$C_6H_{10}O_4S$	α-Thiodilactylic acid (β-modification)	25	0.06–0.001	382	4.3×10^{-4}	(357)
$C_6H_{10}O_4S$	β-Thiodilactylic acid	25	0.06–0.001	382	7.7×10^{-5}	(357)
$C_6H_{10}O_4S$	Thio-α-lactylhydracrylic acid	25	0.06–0.001	382	2.1×10^{-4}	(357)
$C_6H_{10}O_4S_2$	α-Dithiodilactylic acid	25	0.06–0.001	382	8.9×10^{-4}	(357)
$C_6H_{10}O_4S_2$	β-Dithiodilactylic acid	25	0.004–0.001	382	8.9×10^{-5}	(357)
$C_6H_{10}O_4S_2$	Ethylenethioglycolic acid	25	0.06–0.001	382	4.0×10^{-4}	(552)
$C_6H_{10}O_4S_3$	α-Trithiodilactylic acid	25	0.06–0.001	382	7.9×10^{-4}	(357)
$C_6H_{10}O_4Se$	Selenodilactylic acid (a acid, M. P., 145°)	25	0.02–0.0007	376	4.2×10^{-4}	(134)
$C_6H_{10}O_4Se$	Selenodilactylic acid (b acid, M. P., 109°)	25	0.02–0.0007	376	3.8×10^{-4}	(134)
$C_6H_{10}O_5$	Saccharic acid anhydride	25	0.03–0.008	382	1.2×10^{-6}	(569)
$C_6H_{10}O_5$	Isosaccharic acid anhydride	25	0.03–0.008	382	1.7×10^{-6}	(569)
$C_6H_{10}O_6S$	α, α'-Diethylsulfonedicarboxylic acid	25	0.06–0.001	383	1.01×10^{-2}	(357, 359)
$C_6H_{10}O_6S$	β, β'-Diethylsulfonedicarboxylic acid	25	0.008–0.001	383	2.3×10^{-4}	(357)
$C_6H_{10}O_6S_2$	Ethylenesulfoxyacetic acid	25	0.03–0.001	380	$\Lambda_{0.03} = 151$	(552)
$C_6H_{10}O_8$	Mucic acid	25	0.016–0.001	378	6.1×10^{-4}	(378)
$C_6H_{10}O_8$	d-Saccharic acid	25.2	0.12–0.001	380	1.0×10^{-3}	(398); *cf.* (432)
$C_6H_{10}O_8S_2$	Ethylenesulfoneacetic acid	25	0.016–0.001	380	$\Lambda_{0.016} = 253$	(552)
$C_6H_{11}NO_3$	α-Oximinoisohexoic acid	25	0.06–0.004	377	5.5×10^{-4}	(265)
$C_6H_{11}NO_3$	α-Oximino-n-hexoic acid	25	0.03–0.008	377	6.5×10^{-4}	(265)
$C_6H_{11}NO_4$	β-Monoethyl aminosuccinate	25	0.013–0.0008	378	6.7×10^{-6}	(601)
$C_6H_{11}NO_4$	Ethylaminosuccinic acid	25	0.03–0.001	378	3.39×10^{-4}	(371)
$C_6H_{11}NO_4$	Nitrocaproic acid	25	0.016–0.0005	378	1.20×10^{-4}	(436)
$C_6H_{11}N_3O_4$	Ethyl 4-methyl-1, 2-dihydroxy-1, 2, 5-triazole-3-carboxylate	18	0.04–0.008	342	6.1×10^{-3}	(174)
$C_6H_{11}O_7P$	Mannide phosphoric acid	25	0.125–0.002	381	$\Lambda_{0.125} = 208$	(120)
$C_6H_{12}Hg_3O_5$	Trimercurydiacetone hydroxide	18	0.004–0.002	(?)	$\Lambda_{0.004} = 0.02$	(18)
$C_6H_{12}N_4$	Hexamethylenetetramine	[18]	0.5–0.03	199	1.5×10^{-8}	(462)
$C_6H_{12}O_2$	Isobutylacetic acid	25	0.03–0.001	378	1.47×10^{-5}	(53, 200)
$C_6H_{12}O_2$	Caproic acid	25	0.04–0.001	379	1.40×10^{-5}	(53, 163, 200, 436)
$C_6H_{12}O_2$	Isocaproic acid	25	0.04–0.002	379	1.45×10^{-5}	(163)
$C_6H_{12}O_2$	Cyclohexane-1, 2-diol (M. P. 99°)	25	1.0–0.5	(?)	$\Lambda_{1.0} = 0.012$	(74)
$C_6H_{12}O_2$	Cyclohexane-1, 2-diol (M. P. 104°)	25	1.0–0.5	(?)	$\Lambda_{1.0} = 0.004$	(74)
$C_6H_{12}O_2$	Diethylacetic acid	25	0.03–0.0008	379	1.98×10^{-5}	(53, 525.2, 579)
					1.85×10^{-5}	(200, 558)
$C_6H_{12}O_2$	Dimethylethylacetic acid	25	0.03–0.001	379	9.4×10^{-6}	(53)
$C_6H_{12}O_3$	Isobutoxyacetic acid	25	(?)	(?)	2.14×10^{-4}	(438)
$C_6H_{12}O_3$	n-Butoxyacetic acid	25	(?)	(?)	2.19×10^{-4}	(438)
$C_6H_{12}O_3$	γ-Ethoxybutyric acid	25	(?)	(?)	2.00×10^{-5}	(438)
$C_6H_{12}O_3$	α-Hydroxy-α, β, β-trimethylpropionic acid	[25]	(?)	(?)	1.13×10^{-4}	(448)
$C_6H_{12}O_3$	β-Hydroxy-α, β, β-trimethylpropionic acid	25	0.05–0.0016	377	3.4×10^{-5}	(448, 550)
$C_6H_{12}O_3$	δ-Methoxyvaleric acid	25	(?)	(?)	1.91×10^{-5}	(438)
$C_6H_{12}O_3$	Paracetaldehyde	15	0.5–0.016	(?)	$\Lambda_{0.03} = 0.7$	(554)
$C_6H_{12}O_3$	Trimethylethylenelactic acid	25	0.03–0.001	377	2.1×10^{-5}	(550)
$C_6H_{12}O_5$	Rhamnose	25	0.5	(?)	$\Lambda_{0.5} = 0.10$	(71)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_6H_{12}O_6$	Fructose	20	0.4	(?)	$\Lambda_{0.4} = 0.05$	(71, 349, 473)
$C_6H_{12}O_6$	Galactose	25	1.0	(?)	$\Lambda_{1.0} = 0.035$	(117)
$C_6H_{12}O_6$	Glucose	20	0.4–0.1	(?)	$\Lambda_{0.4} = 0.13$	(71, 349, 464, 473)
$C_6H_{12}O_6$	Mannose	25	0.5	(?)	$\Lambda_{0.5} = 0.63$	(71)
$C_6H_{12}O_7$	Gluconic acid	25	0.5–0.03	376	2.5×10^{-4}	(88)
$C_6H_{14}O_2$	Pinacol	25	0.25–0.03	(?)	$\Lambda_{0.25} = 0.06$	(65)
$C_6H_{14}O_3S$	Diethylthetin	25	0.06–0.004	(?)	$\Lambda_{0.06} = 2.15$	(119)
$C_6H_{14}O_3S$	Ethyldimethylthetin	25	0.06–0.004	(?)	$\Lambda_{0.06} = 2.6$	(119)
$C_6H_{14}O_3Se$	Diethylselenetin	25	0.06–0.002	(?)	$\Lambda_{0.06} = 6.3$	(119)
$C_6H_{14}O_6$	*d*-Mannitol	25	0.03	(?)	$\Lambda_{0.03} = 0.17$	(479)
$C_6H_{14}O_6$	Sorbitol	25	2–0.06	(?)	$\Lambda_{0.5} = 0.03$	(65)
$C_6H_{15}N$	Dipropylamine	25	0.12–0.004	228	8.2×10^{-4}	(104)
$C_6H_{15}N$	Triethylamine	25	0.12–0.004	231	5.2×10^{-4}	(104)
		0–50	0.06			(251, 433)
$C_6H_{15}O_4P$	Dipropyl phosphate	25	0.125–0.001	381	$\Lambda_{0.03} = 297$	(164)
$C_6H_{16}OPb$	Lead triethyl hydroxide	25	0.07–0.01	(?)	$\Lambda_{0.07} = 3.8$	(509)
$C_6H_{16}OS$	Triethylsulfonium hydroxide	25	0.06–0.004	234	$\Lambda_{0.06} = 210$	(433)
$C_6H_{16}OSn$	Tin triethyl hydroxide	25	0.07–0.004	(?)	$\Lambda_{0.07} = 0.29$	(509)
$C_7H_3Br_3O_2$	2, 4, 6-Tribromobenzoic acid	25	0.008–0.001	380	3.8×10^{-2}	(598)
$C_7H_4BrClO_3$	3-Hydroxy-2-chloro-6-bromobenzoic acid	25	0.007–0.0009	380	2.2×10^{-2}	(135)
$C_7H_4BrClO_3$	3-Hydroxy-6-chloro-2-bromobenzoic acid	25	0.008–0.001	380	1.95×10^{-3}	(135)
$C_7H_4BrNO_4$	2-Nitro-3-bromobenzoic acid	25	0.001	377	3.2×10^{-3}	(279)
$C_7H_4BrNO_4$	3-Nitro-2-bromobenzoic acid	25	0.004–0.001	377	1.05×10^{-3}	(279)
$C_7H_4BrNO_4$	3-Nitro-4-bromobenzoic acid	25	0.0014–0.0007	377	4.2×10^{-4}	(323)
$C_7H_4BrNO_4$	5-Nitro-2-bromobenzoic acid	25	0.004–0.001	377	8.5×10^{-3}	(279)
$C_7H_4BrNO_4$	6-Nitro-3-bromobenzoic acid	25	0.008–0.001	377	1.35×10^{-2}	(279, 436)
$C_7H_4Br_2O_2$	2, 4-Dibromobenzoic acid	25	0.0025–0.0006	380	2.0×10^{-3}	(323)
$C_7H_4Br_2O_5$	Dibromogallic acid	25	0.03–0.001	378	1.17×10^{-2}	(436)
$C_7H_4ClNO_4$	2-Nitro-3-chlorobenzoic acid	25	0.002–0.001	380	4.0×10^{-3}	(279)
$C_7H_4ClNO_4$	2-Nitro-4-chlorobenzoic acid	25	0.004–0.002	380	9.0×10^{-3}	(49)
$C_7H_4ClNO_4$	3-Nitro-2-chlorobenzoic acid	25	0.004–0.001	380	8.1×10^{-3}	(279)
$C_7H_4ClNO_4$	3-Nitro-4-chlorobenzoic acid	25	0.003–0.0006	380	4.4×10^{-4}	(49, 490)
$C_7H_4ClNO_4$	3-Nitro-5-chlorobenzoic acid	25	0.002–0.0003	380	7.41×10^{-4}	(313)
$C_7H_4ClNO_4$	4-Nitro-2-chlorobenzoic acid	25	0.03–0.002	380	9.9×10^{-3}	(49)
$C_7H_4ClNO_4$	5-Nitro-2-chlorobenzoic acid	25	0.01–0.001	380	6.0×10^{-3}	(49, 279)
$C_7H_4ClNO_4$	6-Nitro-3-chlorobenzoic acid	25	0.014–0.001	380	1.35×10^{-2}	(49, 279)
$C_7H_4Cl_2O_3$	2-Hydroxy-3, 5-dichlorobenzoic acid	25	0.0016–0.0008	380	4.5×10^{-3}	(135)
$C_7H_4Cl_2O_3$	3-Hydroxy-2, 6-dichlorobenzoic acid	25	0.008–0.001	380	2.1×10^{-2}	(135)
$C_7H_4Cl_2O_4$	3, 4-Dihydroxy-2, 5-dichlorobenzoic acid	25	0.03–0.001	380	$\Lambda_{0.03} = 49.6$	(135)
$C_7H_4Cl_2O_4$	3, 4-Dihydroxy-5, 6-dichlorobenzoic acid	25	0.016–0.001	380	$\Lambda_{0.016} = 75.2$	(135)
$C_7H_4FNO_4$	3-Nitro-4-fluorobenzoic acid	25	(?)	(?)	4.33×10^{-4}	(490)
$C_7H_4N_2O_6$	2, 3-Dinitrobenzoic acid	25	0.01–0.0006	380	1.3×10^{-2}	(518)
		40	0.01–0.0006			(518)
$C_7H_4N_2O_6$	2, 4-Dinitrobenzoic acid	25	0.01–0.0006	380	3.5×10^{-2}	(518)
		0–65	0.03–0.0005			(518, 610, 611)
$C_7H_4N_2O_6$	2, 5-Dinitrobenzoic acid	25	0.01–0.0006	380	2.4×10^{-2}	(518)
		40	0.01–0.0006			(518)
$C_7H_4N_2O_6$	2, 6-Dinitrobenzoic acid	25	0.01–0.0006	380	$[\Lambda_{0.01} = 339]$	(518)
		40	0.01–0.0006			(518)
$C_7H_4N_2O_6$	3, 4-Dinitrobenzoic acid	25	0.01–0.0006	380	1.59×10^{-3}	(518)
		40	0.01–0.0006			(518)
$C_7H_4N_2O_6$	3, 5-Dinitrobenzoic acid	25	0.01–0.0001	380	1.55×10^{-3}	(312); *cf.* (49, 518)
		0–65	0.01–0.0005			(518, 610, 611)
$C_7H_4O_6$	Chelidonic acid	25	0.016–0.0005	(?)	$\Lambda_{0.016} = 455$	(436)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_4O_7$	Meconic acid	25	0.03–0.0001	(?)	$\Lambda_{0.03} = 450$	(378, 436)
		0–65	0.03–0.0005			(610, 611)
$C_7H_5BrO_2$	*o*-Bromobenzoic acid	25	0.008–0.001	383	1.42×10^{-3}	(436)
		0–35	0.008–0.0005			(525)
$C_7H_5BrO_2$	*m*-Bromobenzoic acid	25	0.002–0.001	383	1.35×10^{-4}	(436)
		0–35	0.002–0.005			(525)
$C_7H_5BrO_3$	2-Hydroxy-5-bromobenzoic acid	25	0.004–0.0002	381	2.40×10^{-3}	(313)
$C_7H_5BrO_4$	2, 4-Dihydroxy-?-bromobenzoic acid	25	0.002–0.0002	380	1.03×10^{-3}	(313)
$C_7H_5BrO_4$	2, 5-Dihydroxy-?-bromobenzoic acid	25	0.008–0.0002	380	3.90×10^{-3}	(313)
$C_7H_5BrO_5$	Bromogallic acid	25	0.016–0.001	378	5.8×10^{-4}	(436)
$C_7H_5Br_2NO_3$	3, 4-Dibromo-1-methyl-pyrrylglyoxylic acid	25	0.004–0.001	380	[$\Lambda_{0.002} = 367$]	(7)
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid	25	0.016–0.0002	382.5	1.28×10^{-3}	(312, 436)
		0–99	0.008–0.0005			(506, 610, 611)
$C_7H_5ClO_2$	*m*-Chlorobenzoic acid	25	0.004–0.001	383	1.52×10^{-4}	(436)
		0–35	0.002–0.0005			(525)
$C_7H_5ClO_2$	*p*-Chlorobenzoic acid	25	0.0005	383	9.1×10^{-5}	(436)
		0–35	0.0005			(525)
$C_7H_5ClO_3$	2-Hydroxy-5-chlorobenzoic acid	25	0.003–0.0008	381	1.95×10^{-3}	(135)
$C_7H_5ClO_3$	3-Hydroxy-2-chlorobenzoic acid	25	0.004–0.001	381	1.36×10^{-3}	(135)
$C_7H_5ClO_3$	3-Hydroxy-6-chlorobenzoic acid	25	0.016–0.001	381	1.38×10^{-3}	(135)
$C_7H_5ClO_3$	4-Hydroxy-3-chlorobenzoic acid	25	0.008–0.001	381	5.6×10^{-5}	(135)
$C_7H_5FO_2$	*o*-Fluorobenzoic acid	25	0.004–0.001	382	3.15×10^{-4}	(521)
$C_7H_5FO_2$	*m*-Fluorobenzoic acid	25	0.016–0.001	382	1.34×10^{-4}	(436, 521)
$C_7H_5FO_2$	*p*-Fluorobenzoic acid	25	0.004–0.001	382	1.35×10^{-4}	(521); *cf.* (490)
$C_7H_5IO_2$	*o*-Iodobenzoic acid	25	0.006–0.0008	382	1.29×10^{-3}	(14)
		25–99	0.002–0.001			(506)
$C_7H_5IO_2$	*m*-Iodobenzoic acid	25	0.0008–0.0004	382	1.6×10^{-4}	(49)
		60–99	0.002–0.0014			(506)
$C_7H_5IO_3$	*o*-Iodosobenzoic acid	25	0.004–0.001	382	6×10^{-7}	(14)
C_7H_5NO	*p*-Cyanophenol	0	0.03–0.004	246	3×10^{-7}	(226)
		25	0.03–0.004	383	6×10^{-7}	(226)
		35	0.03–0.004	438	8×10^{-7}	(226)
$C_7H_5NO_3S$	*o*-Benzoic sulfimide (saccharin)	25	0.006–0.0016	380	3.7×10^{-3}	(255)
		36.5	0.4–0.00003			(374)
$C_7H_5NO_4$	*o*-Nitrobenzoic acid	10	0.03–0.006	297	8.2×10^{-3}	(425)
		15	0.03–0.006	326	7.6×10^{-3}	(425)
		20	0.04–0.009	354	7.1×10^{-3}	(425)
		25	0.03–0.0002	382	6.4×10^{-3}	(312, 425, 436)
		30	0.04–0.01	410	5.9×10^{-3}	(425)
		0–99	0.03–0.0005			(172, 299, 506, 611)
$C_7H_5NO_4$	*m*-Nitrobenzoic acid	0	0.01–0.0016	244	2.76×10^{-4}	(172)
		20	0.01–0.0016	353	3.09×10^{-4}	(172)
		25	0.016–0.001	381	3.16×10^{-4}	(172)
					3.38×10^{-4}	(436)
		30	0.01–0.0016	410	3.16×10^{-4}	(172)
		35	0.01–0.0016	438	3.14×10^{-4}	(172)
		40	0.01–0.0016	464	3.14×10^{-4}	(172)
		45	0.01–0.0016	487	3.14×10^{-4}	(172)
		50	0.01–0.0016	510	3.13×10^{-4}	(172)
		0–99	0.008–0.0005			(299, 506, 611)
$C_7H_5NO_4$	*p*-Nitrobenzoic acid	25	0.004–0.001	381	3.88×10^{-4}	(436)
		0–65	0.002–0.0005			(610, 611)
$C_7H_5NO_4$	Pyridine-2, 3-dicarboxylic acid	25	0.016–0.004	381	2.95×10^{-3}	(436)
$C_7H_5NO_4$	Pyridine-2, 4-dicarboxylic acid	25	0.008–0.002	381	5.8×10^{-3}	(436, 556)
$C_7H_5NO_4$	Pyridine-2, 5-dicarboxylic acid	25	0.008–0.001	381	4.1×10^{-3}	(436)
$C_7H_5NO_4$	Pyridine-2, 6-dicarboxylic acid	25	0.016–0.0005	381	5.6×10^{-3}	(556)
$C_7H_5NO_4$	Pyridine-3, 4-dicarboxylic acid	25	0.008–0.001	381	2.05×10^{-3}	(436)
$C_7H_5NO_4$	Pyridine-3, 5-dicarboxylic acid	25	0.004–0.0005	381	1.45×10^{-3}	(436)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_5NO_5$	Ammonchelidonic acid	25	0.006–0.0007	(?)	$\Lambda_{0.006} = 391$	(436)
$C_7H_5NO_5$	α-Hydroxyisocinchomeronic acid	25	0.008–0.001	381	1.60×10^{-2}	(436)
$C_7H_5NO_5$	3-Nitro-2-hydroxybenzoic acid	25	0.008–0.001	381	1.5×10^{-2}	(378, 436)
$C_7H_5NO_5$	5-Nitro-2-hydroxybenzoic acid	25	0.004–0.001	381	7.8×10^{-3}	(378); *cf.* (436)
$C_7H_5N_3O_7$	2, 4, 6-Trinitro-*m*-cresol	25	0.008	382	$\Lambda_{0.008} = 352$	(314)
$C_7H_6BrNO_2$	*n*-*p*-Bromophenylnitromethane	0	0.0004	(?)	[$\Lambda_{0.0004} = 2.5$]	(249)
$C_7H_6BrNO_2$	Iso-*p*-bromophenylnitromethane	0	0.003	(?)	$\Lambda_{0.003} = 24$	(249)
$C_7H_6ClNO_2$	3-Amino-2-chlorobenzoic acid	25	0.016–0.001	378	6×10^{-4}	(277)
$C_7H_6ClNO_2$	3-Amino-6-chlorobenzoic acid	25	0.016–0.001	378	7×10^{-5}	(32)
$C_7H_6N_2O_2S$	Benzenesulfonecyanamide	25	0.009–0.001	376	1.27×10^{-5}	(26)
$C_7H_6N_2O_4$	3-Amino-5-nitrobenzoic acid	25	0.01–0.0004	380	2.0×10^{-4}	(49)
$C_7H_6N_2O_4$	*m*-Nitrophenylnitromethane ($NO_2.C_6H_4.CH.NO.OH$)	25	0.003–0.0025	(?)	[$\Lambda_{0.0025} = 70$]	(342); *cf.* (275)
$C_7H_6N_2O_4$	*m*-Nitrophenylnitromethane ($NO_2.C_6H_4.CH_2.NO_2$)	25	0.0016	(?)	$\Lambda_{0.0016} = 6$	(342)
$C_7H_6O_2$	Benzoic acid	0	0.001–0.001	244	5.7×10^{-4}	(172)
		20	0.02–0.001	353	6.16×10^{-4}	(172)
		25	0.02–0.001	383	5.86×10^{-4}	(436)
					6.15×10^{-4}	(172); *cf.* (376, 451, 457, 528)
		30	0.02–0.001	410	6.14×10^{-4}	(172)
		35	0.02–0.001	438	6.14×10^{-4}	(172)
		40	0.02–0.001	464	6.12×10^{-4}	(172)
		45	0.02–0.001	487	6.09×10^{-4}	(172)
		50	0.02–0.001	511	6.05×10^{-4}	(172)
		0–99	0.06–0.0005			(45, 47, 126, 178, 273, 328, 506, 609)
$C_7H_6O_2$	Salicylaldehyde	25	0.03–0.004	383	1.53×10^{-5}	(204); *cf.* (441)
$C_7H_6O_2$	*m*-Hydroxybenzaldehyde	25	0.06–0.016	383	3.5×10^{-6}	(204)
					1.0×10^{-8}	(441)
$C_7H_6O_2$	*p*-Hydroxybenzaldehyde	25	0.06–0.002	383	1.63×10^{-6}	(204)
					2.2×10^{-8}	(441)
$C_7H_6O_3$	2, 4-Dihydroxybenzaldehyde	25	0.008–0.001	381	3.52×10^{-6}	(204)
$C_7H_6O_3$	2, 5-Dihydroxybenzaldehyde	25	0.008–0.001	381	4.2×10^{-5}	(204)
$C_7H_6O_3$	3, 4-Dihydroxybenzaldehyde	25	0.12–0.0002	381	3.05×10^{-5}	(204)
					2.8×10^{-8}	(441)
$C_7H_6O_3$	*allo*-Furfuracrylic acid	(?)	(?)	(?)	7.82×10^{-5}	(346)
$C_7H_6O_3$	Furfuracrylic acid	(?)	(?)	(?)	3.25×10^{-5}	(346)
$C_7H_6O_3$	Salicylic acid	0	0.01–0.0016	245	7.7×10^{-4}	(172)
		20	0.01–0.0016	354	9.5×10^{-4}	(172)
		25	0.014–0.001	384	1.00×10^{-5}	(81, 102.1, 172, 313, 376, 436)
		35	0.01–0.0016	439	1.00×10^{-5}	(102.1, 172)
		40	0.01–0.0016	465	1.00×10^{-5}	(172)
		45	0.01–0.0016	488	1.01×10^{-5}	(172)
		50	0.01–0.0016	512	1.01×10^{-5}	(172)
		0–99	0.016–0.0005			(45, 47, 126, 506, 526, 609)
$C_7H_6O_3$	*m*-Hydroxybenzoic acid	0	0.01–0.0016	244	7.1×10^{-5}	(172)
		20	0.01–0.0016	353	7.61×10^{-5}	(172)
		25	0.03–0.001	383	8.54×10^{-5}	(436)
					7.74×10^{-5}	(81, 172)
		30	0.01–0.0016	410	7.65×10^{-5}	(172)
		35	0.01–0.0016	438	7.60×10^{-5}	(172)
		40	0.01–0.0016	464	7.52×10^{-5}	(172)
		45	0.01–0.0016	487	7.45×10^{-5}	(172)
		50	0.01–0.0016	511	7.38×10^{-5}	(172)
		0–65	0.03–0.0005			(45, 47, 378, 525, 609, 611)
$C_7H_6O_3$	*p*-Hydroxybenzoic acid	25	0.03–0.001	384	2.80×10^{-5}	(81, 341, 436); *cf.* (378)
		0–65	0.016–0.0005			(45, 47, 609, 611)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_6O_4$	2, 3-Dihydroxybenzoic acid	25	0.016–0.0005	383	1.12×10^{-3}	(436)
$C_7H_6O_4$	2, 4-Dihydroxybenzoic acid	25	0.016–0.0005	383	5.05×10^{-4}	(81, 313, 436, 540)
		0–65	0.008–0.0005			(610, 611)
$C_7H_6O_4$	2, 5-Dihydroxybenzoic acid	25	0.016–0.0005	383	1.06×10^{-3}	(81, 313, 436)
		0–35	0.008–0.0005			(610)
$C_7H_6O_4$	2, 6-Dihydroxybenzoic acid	25	0.016–0.001	383	5×10^{-2}	(436)
$C_7H_6O_4$	3, 4-Dihydroxybenzoic acid	25	0.03–0.001	383	3.1×10^{-5}	(66, 378, 436)
$C_7H_6O_4$	3, 5-Dihydroxybenzoic acid	25	0.03–0.001	383	8.9×10^{-5}	(436)
$C_7H_6O_4$	Gallic aldehyde	19.8	0.016	(?)	$\Lambda_{0.016} = 1.25$	(484)
$C_7H_6O_4$	Hydroxyhydroquinol aldehyde	25	0.008–0.001	381	1.77×10^{-5}	(204)
$C_7H_6O_4$	Phloroglucinol aldehyde	25	0.007–0.0008	381	4.25×10^{-5}	(204)
$C_7H_6O_4$	Pyrogallol aldehyde	25	0.004–0.0005	381	1.12×10^{-4}	(204)
$C_7H_6O_5$	Gallic acid	25	0.03–0.001	383	3.8×10^{-5}	(436)
					3.4×10^{-5}	(376)
		0–65	0.016–0.0005			(66, 525, 609)
$C_7H_6O_5$	Phloroglucinolcarboxylic acid	25	0.03–0.001	383	1.9×10^{-2}	(436)
$C_7H_6O_5$	Pyrogallolcarboxylic acid	25	0.016–0.001	383	5.3×10^{-4}	(378, 436)
$C_7H_6O_5S$	*o*-Sulfobenzoic acid	25	0.03–0.0005	[379]	$\Lambda_{0.03} = 376$	(525)
		0–35	0.03–0.0005			(525)
$C_7H_6O_5S$	*m*-Sulfobenzoic acid	25	0.09–0.0014	379	$\Lambda_{0.09} = 324$	(598)
		0–35	0.002–0.0005			(525)
$C_7H_6O_5S$	*p*-Sulfobenzoic acid	25	0.015–0.0004	382	$\Lambda_{0.015} = 375.5$	(601)
$C_7H_6O_6S$	5-Sulfosalicylic acid	25	0.03–0.0005	(?)	$\Lambda_{0.03} = 355$	(526)
		0–65	0.03–0.0005			(526)
$C_7H_7Br_2NO_3S$	3, 5-Dibromo-2-toluidine-4-sulfonic acid	25	0.016–0.002	379	$\Lambda_{0.016} = 287$	(165)
C_7H_7NO	Benzamide	25	0.016–0.001	(?)	$\Lambda_{0.016} = 1.3$	(553)
		0–40	0.016			(429)
C_7H_7NO	Formanilide	25	0.10–0.006	380	5×10^{-10}	(176)
$C_7H_7NO_2$	*o*-Aminobenzoic acid	25	0.016–0.0005	382	$\Lambda_{0.016} = 7.7$	(436, 588, 622)
		0–45	0.016–0.0005			(45, 366, 609)
$C_7H_7NO_2$	*m*-Aminobenzoic acid	25	0.016–0.001	382	$\Lambda_{0.016} = 9.9$	(588, 622)
		0–35	0.016–0.0005			(45, 436, 611)
$C_7H_7NO_2$	*p*-Aminobenzoic acid	25	0.03–0.0005	382	$\Lambda_{0.016} = 8.0$	(436, 588, 622)
		0–35	0.016–0.0005			(45, 609)
$C_7H_7NO_2$	Benzhydroxamic acid	25	0.03–0.015	381	7.5×10^{-7}	(426)
		1–20	0.016–0.008			(429)
$C_7H_7NO_2$	6-Nitroso-*m*-cresol	25	0.008–0.001	380	3.5×10^{-7}	(180)
$C_7H_7NO_3$	1-Methylpyrrylglyoxylic acid	25	0.03–0.001	382	2.6×10^{-2}	(7)
$C_7H_7NO_3$	2-Methylpyrrylketone-5-carboxylic acid	25	0.025–0.0008	380	2.9×10^{-4}	(7, 378)
$C_7H_7NO_3$	4-Nitrosoorcinol (red isomer)	25	0.008–0.001	379	5.0×10^{-4}	(252)
$C_7H_7NO_3$	4-Nitrosoorcinol (yellow isomer)	25	0.008–0.0003	379	4.5×10^{-4}	(180, 522)
					3.6×10^{-4}	(252)
					3.2×10^{-4}	(261)
$C_7H_7NO_3$	Salicylhydroxamic acid	25	0.06–0.008	381	6.3×10^{-6}	(426)
$C_7H_7NO_4S$	*o*-Sulfaminebenzoic acid	25	0.04–0.0001	380	2.05×10^{-3}	(255)
					2.25×10^{-3}	(621); *cf.* (374)
$C_7H_7NO_4S(-H_2O?)$	Iso-*p*-sulfaminebenzoic acid	25	0.03–0.001	380	$\Lambda_{0.03} = 345$	(533)
$C_7H_7NO_4S$	*p*-Sulfaminebenzoic acid	25	0.006–0.0008	380	2.5×10^{-4}	(255); *cf.* (374, 533)
		0–65	0.002–0.0005			(610, 611)
$C_7H_7NO_4S$	*o*-Sulfobenzamide	25	0.02–0.00016	380	$\Lambda_{0.02} = 338$	(621)
$C_7H_7NO_5S$	2-Amino-4-sulfobenzoic acid	25	0.007–0.0008	380	$\Lambda_{0.0067} = 312.0$	(161)
$C_7H_7NO_5S$	3-Amino-4-sulfobenzoic acid	25	0.003–0.0008	380	$\Lambda_{0.003} = 340.1$	(161)
$C_7H_7NO_5S$	4-Amino-2-sulfobenzoic acid	25	0.007–0.0008	380	$\Lambda_{0.0067} = 187.5$	(161)
$C_7H_7NO_5S$	4-Amino-3-sulfobenzoic acid	25	0.007–0.0016	380	$\Lambda_{0.0067} = 349.1$	(161)
$C_7H_7NO_5S$	5-Amino-2-sulfobenzoic acid	25	0.007–0.0008	380	$\Lambda_{0.0067} = 214.2$	(161)
$C_7H_7NO_5S$	5-Amino-3-sulfobenzoic acid	25	0.007–0.0008	380	$\Lambda_{0.0067} = 165.4$	(161)
$C_7H_7NO_5S$	1, 2, 4-*m*-Nitrotoluenesulfonic acid	25	0.12–0.0005	379	$\Lambda_{0.03} = 324$	(610)
		0–35	0.12–0.0005			(610)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_7NO_5S$	1, 4, 2-*m*-Nitrotoluenesulfonic acid	25	0.12–0.0005	379	$\Lambda_{0.03} = 372$	(611)
		0–65	0.12–0.0005			(611)
$C_7H_8BrNO_3S$	?-Bromo-2-toluidine-?-sulfonic acid	25	0.004–0.0005	378	$\Lambda_{0.004} = 169.7$	(165)
$C_7H_8BrNO_3S$	?-Bromo-4-toluidine-2-sulfonic acid	25	0.016–0.0005	378	4.2×10^{-3}	(165)
$C_7H_8BrNO_3S$	3-Bromo-2-toluidine-5-sulfonic acid	25	0.03–0.001	379	$\Lambda_{0.03} = 302$	(165)
$C_7H_8INO_3S$	4-Iodo-2-toluidine-5-sulfonic acid..	25	0.004–0.0002	379	[$\Lambda_{0.004} = 132$]	(165)
$C_7H_8N_2O_2$	*p*-Anisolediazonium hydroxide....	0	0.008–0.002	137	$\Lambda_{0.008} = 116$	(166)
$C_7H_8N_2O_2$	3, 5-Diaminobenzoic acid.....	25	0.03–0.0018	379	5×10^{-6}	(49)
$C_7H_8N_2O_2$	*β*-Nitrosobenzylhydroxylamine....	0	0.002	(?)	5.8×10^{-6}	(227)
		25	0.002	(?)	6.5×10^{-6}	(227)
$C_7H_8N_2O_5S$	2-Nitro-4-toluidine-5-sulfonic acid.	25	0.008–0.0002	379	$\Lambda_{0.008} = 322$	(165)
$C_7H_8N_4O_2$	3, 7-Dimethyl-2, 6-dioxypurine....	18	0.0016–0.0008	336	$\Lambda_{0.0016} = 1.0$	(439)
		25	0.0016–0.0008	375	$\Lambda_{0.0016} = 1.7$	(439)
C_7H_8O	*o*-Cresol.....	25	0.05–0.03	382	4.2×10^{-8}	(26)
C_7H_8O	*m*-Cresol.....	25	0.05–0.006	382	1.7×10^{-8}	(26)
C_7H_8O	*p*-Cresol.....	25	0.07–0.009	382	1.1×10^{-8}	(26)
$C_7H_8O_2$	2, 6-Dimethylpyrone.....	25	0.03–0.002	233	6×10^{-9}	(572)
$C_7H_8O_2$	Guaiacol.....	25	0.04–0.005	383	$\Lambda_{0.04} = 0.4$	(26)
$C_7H_8O_2$	Orcinol.....	25	0.04–0.005	382	$\Lambda_{0.01} = 0.5$	(26)
$C_7H_8O_2S$	*o*-Toluenesulfinic acid.....	25	0.03–0.001	379	$\Lambda_{0.03} = 210$	(15)
$C_7H_8O_2S$	*p*-Toluenesulfinic acid.....	18	0.03–0.001	339	$\Lambda_{0.03} = 181$	(15)
		25	0.03–0.001	379	$\Lambda_{0.03} = 213$	(15)
		30	0.03–0.001	407	$\Lambda_{0.03} = 223$	(15)
$C_7H_8O_3$	2, 4-Dimethylfurfurane-3-carboxylic acid.....	25	0.002–0.001	381	1.09×10^{-5}	(183)
$C_7H_8O_3S$	*o*-Anisolesulfinic acid.....	25	0.03–0.001	379	$\Lambda_{0.03} = 208$	(15)
$C_7H_8O_3S$	Benzylsulfonic acid.....	25	0.12–0.001	379	$\Lambda_{0.03} = 363$	(143)
$C_7H_8O_3S$	*p*-Toluenesulfonic acid.....	25	0.20–0.0005	380	$\Lambda_{0.03} = 358$	(143, 145, 312, 603)
		0–65	0.03–0.0005			(145, 610, 611)
$C_7H_8O_4$	Piperylenedicarboxylic acid.....	25	0.03–0.001	380	1.14×10^{-4}	(514)
$C_7H_8O_6$	*β*, *γ*-Dicarboxy-*γ*-valerolactone....	25	0.03–0.008	377	6×10^{-3}	(578)
$C_7H_9BrN_2O_3S$	Bromo-2, 6-toluylenediamine-4-sulfonic acid.....	25	0.007–0.001	379	1.69×10^{-4}	(436)
C_7H_9N	Benzylamine.....	25	0.12–0.004	232	2.0×10^{-5}	(104)
		0–55	0.06			(251)
C_7H_9N	2, 6-Dimethylpyridine.....	25	0.03–0.004	232	1.0×10^{-7}	(414)
$C_7H_9NO_2$	2, 4-Dimethylpyrrole-3-carboxylic acid.....	25	0.004–0.001	381	7.4×10^{-7}	(7)
$C_7H_9NO_2$	2, 4-Dimethylpyrrole-5-carboxylic acid.....	25	0.0013–0.0006	381	2×10^{-6}	(7)
$C_7H_9NO_2$	2, 5-Dimethylpyrrole-3-carboxylic acid.....	25	0.003–0.0008	381	1.1×10^{-6}	(7)
$C_7H_9NO_3$	Ethyl cyanoacetoacetate.....	25	0.016–0.001	379	6.2×10^{-4}	(213)
$C_7H_9NO_3$	Methyl cyanopropionylacetate....	25	0.004–0.001	378	7.0×10^{-4}	(214)
$C_7H_9NO_3S$	*p*-Aminobenzylsulfonic acid.....	25	0.008–0.001	379	2.29×10^{-5}	(165)
$C_7H_9NO_3S$	1-Methylaniline-4-sulfonic acid....	25	0.008–0.0005	377	6.52×10^{-4}	(165)
$C_7H_9NO_3S$	2-Toluidine-4-sulfonic acid.....	25	0.03–0.001	379	2.4×10^{-4}	(102, 165, 436)
$C_7H_9NO_3S$	2-Toluidine-5-sulfonic acid.....	25	0.03–0.001	379	7.36×10^{-4}	(102, 165, 436)
$C_7H_9NO_3S$	3-Toluidine-2-sulfonic acid.....	25	0.008–0.001	379	3.50×10^{-4}	(165, 436)
$C_7H_9NO_3S$	4-Toluidine-?-sulfonic acid.....	25	0.016–0.001	380	7.6×10^{-4}	(436)
$C_7H_9NO_3S$	4-Toluidine-2-sulfonic acid.....	25	0.03–0.005	379	4.00×10^{-5}	(102, 165)
$C_7H_9NO_3S$	4-Toluidine-3-sulfonic acid.....	25	0.03–0.001	379	8.33×10^{-4}	(102, 165)
$C_7H_9NO_6S_2$	2-Toluidine-3, 5-disulfonic acid....	25	0.016–0.0005	380	$\Lambda_{0.016} = 354$	(165)
$C_7H_9NO_6S_2$	3-Toluidine-2, 4-disulfonic acid....	25	0.03–0.0005	380	$\Lambda_{0.016} = 90.2$	(165)
$C_7H_9N_3O_5S$	2-Nitro-4-tolylhydrazine-5-sulfonic acid.....	25	0.002–0.0002	376	1×10^{-4}	(165)
$C_7H_{10}AsNO_3$	*o*-Toluidinearsonic acid.....	25	0.016–0.001	372	5.3×10^{-5}	(356)
$C_7H_{10}AsNO_3$	*m*-Toluidinearsonic acid.....	25	0.008–0.001	372	1.3×10^{-4}	(355)
$C_7H_{10}Br_2O_5$	Dibromohydroshikimic acid.....	12	0.02–0.003	314	7.5×10^{-3}	(177)
$C_7H_{10}N_2O_3S$	2, 4-Toluylenediamine-5-sulfonic acid.....	25	0.004–0.00025	376	2.10×10^{-4}	(165)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_{10}N_2O_3S$	2, 6-Toluylenediamine-4-sulfonic acid	25	0.016–0.001	379	4.6×10^{-5}	(436)
$C_7H_{10}O_2$	*m*-Methyldihydroresorcinol	25	0.06–0.001	379	5.6×10^{-6}	(508)
$C_7H_{10}O_2$	Δ^1-Tetrahydrobenzoic acid:					
	(*a*) Liquid phase	25	0.03–0.001	380	2.10×10^{-5}	(13)
	(*b*) Solid phase	25	0.03–0.001	380	2.18×10^{-5}	(13)
$C_7H_{10}O_2$	Δ^2-Tetrahydrobenzoic acid	25	0.06–0.001	380	3.0×10^{-5}	(13)
$C_7H_{10}O_3$	Hexic acid	25	0.016–0.004	378	8.3×10^{-5}	(569)
$C_7H_{10}O_4$	Allylsuccinic acid	25	0.03–0.001	379	1.07×10^{-4}	(577)
$C_7H_{10}O_4$	1, 2-Dimethylcyclopropane-1, 2-dicarboxylic acid	25	0.04–0.005	380	9.90×10^{-5}	(264)
$C_7H_{10}O_4$	α, α'-Dimethylglutaconic acid	25	0.03–0.001	378	1.27×10^{-4}	(550)
$C_7H_{10}O_4$	α-Ethylideneglutaric acid	25	0.03–0.001	380	3.2×10^{-5}	(408)
$C_7H_{10}O_4$	Ethylitaconic acid	25	0.06–0.001	378	3.5×10^{-5}	(191)
$C_7H_{10}O_4$	Ethyl hydroxymethyleneacetoacetate	3.7	0.016–0.002	262	2.3×10^{-5}	(124)
		23.5	0.04–0.002	368	2.9×10^{-5}	(124)
$C_7H_{10}O_4$	Hydroxypimelic acid anhydride	25	0.03–0.001	378	2.72×10^{-5}	(615)
$C_7H_{10}O_4$	α-Monoethyl mesaconate	25	0.03–0.001	380	3.38×10^{-4}	(9)
$C_7H_{10}O_4$	β-Monoethyl mesaconate	25	0.03–0.001	379	5.5×10^{-4}	(9)
$C_7H_{10}O_4$	Methylenedimethylsuccinic acid	25	0.10–0.012	378	1.64×10^{-4}	(92)
$C_7H_{10}O_4$	Methylethylmaleic acid	25	0.03–0.001	379	9.4×10^{-5}	(334, 577)
$C_7H_{10}O_4$	*cis*-Pentamethylene-1, 2-dicarboxylic acid	25	(?)	378	1.58×10^{-4}	(447)
$C_7H_{10}O_4$	*trans*-Pentamethylene-1, 2-dicarboxylic acid	25	0.016–0.0009	378	1.16×10^{-4}	(524, 582)
$C_7H_{10}O_4$	*cis*-Pentamethylene-1, 3-dicarboxylic acid	25	0.06–0.001	378	5.2×10^{-5}	(460)
$C_7H_{10}O_4$	*trans*-Pentamethylene-1, 3-dicarboxylic acid	25	0.06–0.001	378	4.9×10^{-5}	(460)
$C_7H_{10}O_4$	Propenylsuccinic acid	25	0.06–0.001	378	5.8×10^{-5}	(191)
$C_7H_{10}O_4$	Propylfumaric acid	25	0.016–0.001	379	9.1×10^{-4}	(577)
$C_7H_{10}O_4$	Teraconic acid	25	0.02–0.0013	378	1.38×10^{-4}	(524)
$C_7H_{10}O_4$	Terebic acid	25	0.03–0.001	378	2.6×10^{-4}	(436)
$C_7H_{10}O_5$	Dimethyl acetylmalonate	25	0.008	(?)	$[\Lambda_{0.008} = 12]$	(213)
$C_7H_{10}O_5$	Dimethyldihydroxyglutaric lactone	25	0.02–0.0007	379	5×10^{-3}	(631)
$C_7H_{10}O_5$	Hydrochelidonic acid	25	0.06–0.002	378	4.5×10^{-5}	(378)
$C_7H_{10}O_5$	Shikimic acid	14.1	0.01–0.0002	323	7.1×10^{-5}	(177)
$C_7H_{10}O_6$	Acetyl-β-hydroxyglutaric acid	25	0.02–0.003	377	1.54×10^{-4}	(84)
		0	0.02–0.003			(84)
$C_7H_{10}O_6$	Butenyltricarboxylic acid	25	0.03–0.001	378	3.26×10^{-3}	(578)
$C_7H_{10}O_6$	Isobutenyltricarboxylic acid	25	0.03–0.001	378	3.26×10^{-3}	(578)
$C_7H_{10}O_6$	β-Dimethylethenyltricarboxylic acid	25	0.03–0.002	377	4.9×10^{-3}	(578)
$C_7H_{10}O_6$	*fum.*-α-Methyltricarballylic acid	25	0.05–0.001	376	3.15×10^{-4}	(98, 578)
$C_7H_{10}O_6$	*mal.*-α-Methyltricarballylic acid	25	0.05–0.006	375	4.75×10^{-4}	(98)
$C_7H_{10}O_6$	α-Monomethyl tricarballylate	25	0.14–0.016	375	7.5×10^{-5}	(98)
$C_7H_{10}O_6$	β-Monomethyl tricarballylate	25	0.09–0.001	375	9.3×10^{-5}	(98)
$C_7H_{10}O_6S_3$	Methinetrithioglycolic acid	25	0.03–0.002	378	9.1×10^{-4}	(281)
$C_7H_{11}NO_3$	*dl*-Ecgoninic acid	25	0.03–0.0015	376	8.3×10^{-5}	(617)
$C_7H_{11}NO_4$	*N*-Methylpyrrolidine-α, α'-dicarboxylic acid	25	0.06–0.001	(?)	$\Lambda_{0.06} = 136$	(618)
$C_7H_{11}NO_6$	Diethyl nitromalonate	25	0.012–0.006	378	7.2×10^{-4}	(233)
$C_7H_{12}O_2$	α-Ethyl-α, β-pentenic acid	25	0.016–0.001	378	2.1×10^{-5}	(189)
$C_7H_{12}O_2$	α-Ethyl-β, γ-pentenic acid	25	0.03–0.001	378	3.5×10^{-5}	(189)
$C_7H_{12}O_2$	α, β-Heptenic acid	25	0.016–0.001	379	1.5×10^{-5}	(494)
$C_7H_{12}O_2$	Hexahydrobenzoic acid	25	0.016–0.0008	378	1.28×10^{-5}	(361, 525.2, 635)
$C_7H_{12}O_2$	1-Methylpentamethylene-2-carboxylic acid	25	0.02–0.001	378	1.05×10^{-5}	(635)
$C_7H_{12}O_3$	δ-Acetovaleric acid	25	0.02–0.001	378	1.90×10^{-5}	(150)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_{12}O_3$	α-Dimethyllevulinic acid	25	(?)	(?)	1.08×10^{-5}	(61)
$C_7H_{12}O_3$	α-Ethyl-β-acetylpropionic acid	25	(?)	(?)	2.93×10^{-5}	(61)
$C_7H_{12}O_3$	β-Methyl-γ-acetylbutyric acid	25	0.06–0.001	377	2.65×10^{-5}	(508)
$C_7H_{12}O_4$	Butylmalonic acid	25	0.03–0.002	380	1.01×10^{-3}	(390, 577)
		0–65	0.03–0.0005			(526)
$C_7H_{12}O_4$	Isobutylmalonic acid	25	0.03–0.001	380	8.82×10^{-4}	(390, 577)
$C_7H_{12}O_4$	Diethylmalonic acid	25	0.03–0.004	380	7.1×10^{-3}	(390, 577)
		0–65	1.0–0.0005			(68, 526)
$C_7H_{12}O_4$	β, β-Dimethylglutaric acid	25	0.03–0.001	377	2.2×10^{-4}	(451)
					2.0×10^{-4}	(20, 525.2)
$C_7H_{12}O_4$	*fum.-sym.*-Dimethylglutaric acid	25	0.03–0.0006	377	5.7×10^{-5}	(19, 470, 550); *cf.* (49, 577)
$C_7H_{12}O_4$	*mal.-sym.*-Dimethylglutaric acid	25	0.03–0.0009	377	5.3×10^{-5}	(19, 49, 94, 470, 550, 577, 631)
$C_7H_{12}O_4$	Monoethyl dimethylmalonate	25	0.02–0.0007	376	3.04×10^{-4}	(582)
$C_7H_{12}O_4$	α-Monomethyl *asym.*-dimethylsuccinate	25	0.05–0.005	376	2.28×10^{-5}	(100)
$C_7H_{12}O_4$	β-Monomethyl *asym.*-dimethylsuccinate	25	0.09–0.005	376	2.6×10^{-5}	(100)
$C_7H_{12}O_4$	Monomethyl *sym.-anti*-dimethylsuccinate	25	0.05–0.006	376	4.5×10^{-5}	(100)
$C_7H_{12}O_4$	Monomethyl *sym.-p*-dimethylsuccinate	25	0.03–0.004	376	6.0×10^{-5}	(100)
$C_7H_{12}O_4$	α-Ethylglutaric acid	25	0.02–0.0005	377	5.5×10^{-5}	(391)
					5.8×10^{-5}	(20, 451)
$C_7H_{12}O_4$	β-Ethylglutaric acid	25	0.03–0.001	(?)	5.3×10^{-5}	(525.5)
$C_7H_{12}O_4$	Monoethyl ethylmalonate	25	0.03–0.001	376	4.01×10^{-4}	(582)
$C_7H_{12}O_4$	Diethyl malonate	25	0.04–0.01	379	1.2×10^{-8}	(568, 573); *cf.* (275)
$C_7H_{12}O_4$	α-Methyladipic acid	24.4	0.02–0.001	376	4.0×10^{-5}	(391)
$C_7H_{12}O_4$	*fum.-sym.*-Methylethylsuccinic acid	25	0.03–0.001	378	2.05×10^{-4}	(20, 21, 49, 451, 577)
$C_7H_{12}O_4$	*mal.-sym.*-Methylethylsuccinic acid	25	0.03–0.001	378	2.00×10^{-4}	(21, 49, 451, 577)
$C_7H_{12}O_4$	Methylpropylmalonic acid	25	0.06–0.001	377	1.82×10^{-3}	(390)
$C_7H_{12}O_4$	Methylisopropylmalonic acid	25	0.03–0.001	377	1.2×10^{-3}	(390)
$C_7H_{12}O_4$	*n*-Pimelic acid	25	0.03–0.001	377	3.20×10^{-5}	(524, 565)
$C_7H_{12}O_4$	γ-Pimelic acid	25	0.03–0.001	377	4.12×10^{-5}	(577, 582, 631)
					3.92×10^{-5}	(436)
$C_7H_{12}O_4$	Isopimelic acid	25	0.03–0.001	377	9.5×10^{-5}	(577)
					3.40×10^{-5}	(385)
					3.50×10^{-5}	(21, 58, 577)
$C_7H_{12}O_4$	Propylsuccinic acid	25	0.03–0.002	377	8.7×10^{-5}	(569, 577)
$C_7H_{12}O_4$	Isopropylsuccinic acid	25	0.016–0.001	377	7.4×10^{-5}	(569, 577)
$C_7H_{12}O_4$	Trimethylsuccinic acid	25	0.03–0.001	377	3.1×10^{-4}	(25, 95, 561, 577, 631, 632)
$C_7H_{12}O_5$	α, α′-Dimethyl-β-hydroxyglutaric acid	25	0.014–0.0008	376	1.06×10^{-4}	(471, 550)
$C_7H_{12}O_5$	Hydroshikimic acid	19	0.3–0.02	348	3.0×10^{-5}	(177)
$C_7H_{12}O_5$	Hydroxytrimethylsuccinic acid	25	0.07–0.0004	378	9.2×10^{-4}	(92)
					8.3×10^{-4}	(22)
$C_7H_{12}O_6$	Dimethyldihydroxyglutaric acid	25	0.03–0.0009	379	1.7×10^{-3}	(631)
$C_7H_{12}O_6$	*dl*-Quinic acid	9	0.15–0.005	303	2.2×10^{-4}	(177)
$C_7H_{12}O_6$	Quinic acid	14.1	0.13–0.0005	314	2.9×10^{-4}	(177)
		25	0.03–0.002	376	2.8×10^{-4}	(378, 527)
$C_7H_{12}O_7$	Dihydroxyhydroshikimic acid	19	0.05–0.003	347	7.1×10^{-4}	(177)
$C_7H_{14}O_2$	Heptoic acid	25	0.01–0.001	378	1.30×10^{-5}	(200); *cf.* (163)
$C_7H_{14}O_3$	β-Diethylethylenelactic acid	25	0.03–0.0009	376	2.97×10^{-5}	(550)
$C_7H_{14}O_3$	Dimethylethylethylenelactic acid	25	0.03–0.001	376	1.48×10^{-5}	(550)
$C_7H_{14}O_3$	Tetramethylethylenelactic acid	25	0.03–0.001	376	4.27×10^{-5}	(550)
$C_7H_{14}O_6$	α-Methylglucoside	25	0.5	(?)	$\Lambda_{0.5} = 0.05$	(71)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_7H_{14}O_6$	β-Methylglucoside	25	0.5	(?)	$\Lambda_{0.5} = 0.05$	(71)
$C_8H_2Cl_4O_4$	Tetrachlorophthalic acid	25	0.002–0.0005	[378]	$\Lambda_{0.002} = 470$	(610)
		0–65	0.002–0.0005			(610, 611)
$C_8H_4Cl_2O_4$	3, 6-Dichlorophthalic acid	25	0.03–0.001	379	3.4×10^{-2}	(598)
$C_8H_4Cl_2O_4$	4, 5-Dichlorophthalic acid	25	0.008–0.0005	379	$\Lambda_{0.008} = 306$	(610)
		0–65	0.008–0.0005			(610, 611)
$C_8H_5BrO_4$	2-Bromoterephthalic acid	25	0.006–0.001	379	6×10^{-3}	(598)
$C_8H_5ClO_4$	4-Chlorophthalic acid	25	0.016–0.004	380	$\Lambda_{0.016} = 276$	(436)
$C_8H_5NO_2$	*m*-Cyanobenzoic acid	25	0.008–0.001	380	1.95×10^{-4}	(436)
$C_8H_5NO_2$	Phthalimide	25	0.0022–0.0018	378	$[4 \times 10^{-8}]$	(362); *cf.* (624)
$C_8H_5NO_5$	2-Aldehydo-3-nitrobenzoic acid	25	0.008–0.001	380	1.30×10^{-6}	(540)
$C_8H_5NO_5$	2-Aldehydo-5-nitrobenzoic acid	25	0.008–0.001	380	9.8×10^{-5}	(540)
$C_8H_5NO_5S$	Sulfimidophthalic acid	25	0.01–0.005	(?)	$\Lambda_{0.01} = 338$	(637)
$C_8H_5NO_6$	3-Nitrophthalic acid	25	0.06–0.001	378	1.25×10^{-2}	(436, 598)
$C_8H_5NO_6$	2-Nitroterephthalic acid	25	0.05–0.002	378	1.9×10^{-2}	(598)
$C_8H_5NO_6$	4-Nitrophthalic acid	25	0.03–0.001	378	7.5×10^{-3}	(436, 598)
$C_8H_5NO_6$	4-Nitroisophthalic acid	25	0.03–0.001	378	$\Lambda_{0.03} = 166.7$	(601)
$C_8H_5NO_6$	Pyridine-2, 3, 4-tricarboxylic acid	25	0.016–0.0002	(?)	$\Lambda_{0.008} = 307$	(436)
$C_8H_5NO_6$	Pyridine-2, 3, 5-tricarboxylic acid	25	0.008–0.0002	(?)	$\Lambda_{0.008} = 295$	(436)
$C_8H_5NO_6$	Pyridine-3, 4, 5-tricarboxylic acid	25	0.008–0.0002	(?)	$\Lambda_{0.008} = 248$	(436)
$C_8H_5N_5O_6$	Purpuric acid	0	0.002	240	2×10^{-2}	(248)
$C_8H_6BrClO_5$	Methyl 2-chloro-6-bromogallate	25	0.03–0.004	374	4×10^{-6}	(135)
$C_8H_6BrN_3O$	*p*-Bromophenylcyanourea	25	0.0005	380	2.4×10^{-4}	(64)
$C_8H_6Br_2O_5$	Methyl dibromogallate	25	0.03–0.004	375	1.1×10^{-6}	(135)
$C_8H_6ClNO_3$	*o*-Chlorooxanilic acid	25	0.03–0.001	377	1.95×10^{-2}	(436)
$C_8H_6ClNO_3$	*p*-Chlorooxanilic acid	25	0.004–0.001	377	1.30×10^{-2}	(436)
$C_8H_6Cl_2O_3$	2-Methoxy-3, 5-dichlorobenzoic acid	25	0.0005–0.0002	379	1.3×10^{-3}	(135)
$C_8H_6Cl_2O_4$	Methyl 3, 4-dihydroxy-2, 5-dichlorobenzoate	25	0.004–0.001	377	4.4×10^{-6}	(135)
$C_8H_6Cl_2O_5$	Methyl 2, 6-dichlorogallate	25	0.03–0.004	375	5.8×10^{-7}	(135)
$C_8H_6N_2O$	*N*-Cyanobenzamide	25	0.03–0.0007	380	2.0×10^{-3}	(237)
					1.8×10^{-3}	(26)
$C_8H_6N_2O_2$	Dihydroxyquinazoline	25	0.002	(?)	$\Lambda_{0.002} = 2.9$	(85)
$C_8H_6N_2O_2$	Isatoxime	25	0.002–0.001	377	$[2 \times 10^{-10}]$	(235)
$C_8H_6N_4O_3$	Alloxanthine	25	0.008–0.001	375	$\Lambda_{0.004} = 46.4$	(85, 557)
$C_8H_6O_3$	Benzoylformic acid	25	0.07–0.008	378	4.8×10^{-2}	(69)
$C_8H_6O_3$	Phenylglyoxylic acid	25	0.03–0.001	379	6×10^{-2}	(26)
$C_8H_6O_3$	Phthalaldehydic acid	25	0.02–0.0013	380	3.10×10^{-5}	(601)
$C_8H_6O_4$	Phthalic acid	25	0.06–0.0008	380	1.17×10^{-3}	(330, 436, 476)
		0–65	0.03–0.0005			(45, 126, 328, 526, 609)
$C_8H_6O_4$	Isophthalic acid	25	0.002–0.001	380	2.80×10^{-4}	(436)
		0	0.002–0.0004			(328)
$C_8H_6O_4S$	Thienylpyroracemic acid	25	0.004–0.001	380	4.5×10^{-3}	(7)
$C_8H_6O_5$	2-Hydroxyterephthalic acid	25	0.005–0.0012	379	2.65×10^{-3}	(436, 598)
$C_8H_6O_5$	4-Hydroxyphthalic acid	25	0.06–0.001	378	1.20×10^{-3}	(598)
$C_8H_7BrO_2$	Phenylbromoacetic acid	25	0.01–0.0005	380	3.5×10^{-3}	(515)
$C_8H_7ClO_2$	Phenylchloroacetic acid	25	0.02–0.0005	380	4.3×10^{-3}	(513, 515)
$C_8H_7ClO_3$	3-Methoxy-6-chlorobenzoic acid	25	0.002–0.0005	379	1.3×10^{-3}	(135)
$C_8H_7ClO_5$	Methyl 2-chlorogallate	25	0.03–0.004	376	2.5×10^{-7}	(135)
$C_8H_7NO_3$	1^2-Nitroacetophenone	25	0.004–0.001	376	6.1×10^{-5}	(254)
$C_8H_7NO_3$	Oxanilic acid	25	0.03–0.002	377	1.17×10^{-2}	(422, 436)
$C_8H_7NO_3$	Phenylglyoxylic acid *anti*-oxime	25	0.06–0.015	380	1.5×10^{-2}	(244)
$C_8H_7NO_3$	Phenylglyoxylic acid *syn*-oxime	25	0.06–0.001	380	1.75×10^{-3}	(26, 265)
					1.52×10^{-3}	(244, 265)
$C_8H_7NO_3$	*o*-Phthalamic acid	25	0.03–0.001	379	1.57×10^{-4}	(436)
$C_8H_7NO_4$	2-Aminoterephthalic acid	25	0.002–0.001	379	2.6×10^{-4}	(540)
$C_8H_7NO_4$	3-Methyl-4-nitrobenzoic acid	25	0.001–0.0005	379	3.1×10^{-4}	(601)
$C_8H_7NO_4$	2-Methylpyridine-3, 5-dicarboxylic acid	25	0.008–0.001	379	1.95×10^{-3}	(436)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_8H_7NO_4$	α-Monomethyl pyridine-2, 3-dicarboxylate	25	0.016–0.0005	379	2.60×10^{-3}	(319)
$C_8H_7NO_4$	β-Monomethyl pyridine-2, 3-dicarboxylate	25	0.016–0.0005	379	1.38×10^{-3}	(319)
$C_8H_7NO_4$	β-Monomethyl pyridine-3, 4-dicarboxylate	25	0.016–0.0005	379	6.52×10^{-4}	(319)
$C_8H_7NO_4$	γ-Monomethyl pyridine-3, 4-dicarboxylate	25	0.016–0.0005	379	6.5×10^{-4}	(319)
$C_8H_7NO_4$	2-Pyrroylpyroracemic acid	25	0.005–0.0006	380	8.8×10^{-4}	(7)
$C_8H_7NO_5$	o-Nitrophenoxyacetic acid	25	0.016–0.001	378	1.55×10^{-3}	(436)
$C_8H_7NO_5$	p-Nitrophenoxyacetic acid	25	0.008–0.001	378	1.50×10^{-3}	(436)
$C_8H_7NO_6$	4-Nitro-2-hydroxy-5-methoxybenzoic acid	15	0.004–0.001	319	8.5×10^{-3}	(323)
		25	0.008–0.001	378	1.0×10^{-2}	(323)
		35	0.004–0.001	432	1.0×10^{-2}	(323)
$C_8H_7NO_6$	5-Nitro-2-hydroxy-3-methoxybenzoic acid	15	0.004–0.001	319	8.0×10^{-3}	(323)
		25	0.004–0.001	378	9.0×10^{-3}	(323)
		35	0.004–0.001	432	9.5×10^{-3}	(323)
$C_8H_7NO_6$	5-Nitro-3-hydroxy-4-methoxybenzoic acid	15	0.004–0.001	319	2.65×10^{-4}	(323)
		25	0.004–0.001	378	2.70×10^{-4}	(323)
		35	0.004–0.001	432	2.75×10^{-4}	(323)
$C_8H_7NO_6$	5-Nitro-4-hydroxy-3-methoxybenzoic acid	15	0.004–0.001	319	1.65×10^{-4}	(323)
		25	0.004–0.001	378	1.70×10^{-4}	(323)
		35	0.004–0.001	432	1.50×10^{-4}	(323)
$C_8H_7NO_6$	Nitrovanillic acid	25	0.016–0.004	378	1.15×10^{-4}	(49)
$C_8H_7NO_6S$	Sulfaminephthalic acid	25	0.01–0.005	(?)	$\Lambda_{0.01} = 209$	(637)
$C_8H_7N_3$	C-Phenylosotriazole	20	0.004	(?)	$\Lambda_{0.004} = 3.96$	(429)
		0.5–40	0.004			(429)
$C_8H_7N_3OS$	1-Phenyl-3-thiourazole	25	0.016–0.004	379	1.7×10^{-2}	(6)
$C_8H_7N_3O_2$	1-Phenylurazole	25	0.002–0.0001	380	1.1×10^{-5}	(6)
$C_8H_8O_2$	2-Hydroxy-m-toluic aldehyde	25	0.008–0.001	380	1.49×10^{-5}	(204)
$C_8H_8O_2$	4-Hydroxy-m-toluic aldehyde	25	0.008–0.0005	380	2.13×10^{-5}	(204)
$C_8H_8O_2$	6-Hydroxy-m-toluic aldehyde	25	0.008–0.001	380	4.57×10^{-6}	(204)
$C_8H_8O_2$	5-Hydroxy-o-toluic aldehyde	25	0.008–0.001	380	2.86×10^{-6}	(204)
$C_8H_8O_2$	3-Hydroxy-p-toluic aldehyde	25	0.004–0.0005	380	7.5×10^{-6}	(204)
$C_8H_8O_2$	Phenylacetic acid	25	0.03–0.001	381	5.45×10^{-5}	(436); *cf.* (537)
		0–65	0.03–0.0005			(526, 608, 609)
$C_8H_8O_2$	α-Isophenylacetic acid	25	0.013–0.0011	381	3.70×10^{-5}	(486)
$C_8H_8O_2$	β-Isophenylacetic acid (γ-cycloheptatrienecarboxylic acid)	25	0.016–0.001	381	4.02×10^{-5}	(486)
					3.74×10^{-5}	(616)
$C_8H_8O_2$	δ-Isophenylacetic acid	25	0.016–0.001	381	3.88×10^{-5}	(616)
$C_8H_8O_2$	o-Toluic acid	0	0.003–0.001	243	1.34×10^{-4}	(172)
		20	0.003–0.001	353	1.20×10^{-4}	(172)
		25	0.008–0.001	382	1.17×10^{-4}	(172, 436, 451)
		30	0.003–0.001	410	1.10×10^{-4}	(172)
		35	0.003–0.001	438	1.05×10^{-4}	(172)
		40	0.003–0.001	464	1.00×10^{-4}	(172)
		45	0.003–0.001	487	9.6×10^{-5}	(172)
		50	0.003–0.001	511	9.2×10^{-5}	(172)
		0–99	0.008–0.0005			(506, 525, 609)
$C_8H_8O_2$	m-Toluic acid	25	0.008–0.001	381	5.05×10^{-5}	(436, 451)
		0–99	0.002–0.0005			(506, 525, 609)
$C_8H_8O_2$	p-Toluic acid	25	0.004–0.0005	387	5.05×10^{-5}	(436)
					4.55×10^{-5}	(457)
					3.80×10^{-5}	(451)
		0–99	0.002–0.0005			(506, 525, 609)
$C_8H_8O_2$	*pseudo*-m-Toluic acid	[25]	(?)	(?)	1.3×10^{-4}	(449)
$C_8H_8O_3$	o-Hydroxymethylbenzoic acid	25	0.02–0.0003	378	1.45×10^{-4}	(128, 269)

C-Table.—The C-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_8H_8O_3$	2-Hydroxy-*m*-toluic acid	25	0.002–0.0005	380	1.00×10^{-3}	(378, 457, 536)
$C_8H_8O_3$	4-Hydroxy-*m*-toluic acid	25	0.004–0.0005	380	8.6×10^{-4}	(378, 457, 536)
$C_8H_8O_3$	3-Hydroxy-*o*-toluic acid	25	0.0009	380	1.04×10^{-3}	(536)
$C_8H_8O_3$	6-Hydroxy-*o*-toluic acid	25	0.004–0.0005	381	1.66×10^{-4}	(457)
$C_8H_8O_3$	3-Hydroxy-*p*-toluic acid	25	0.004–0.0005	380	7.2×10^{-4}	(378, 457, 536)
$C_8H_8O_3$	*o*-Methoxybenzoic acid	25	0.03–0.001	381	8.0×10^{-5}	(436)
					8.7×10^{-5}	(457)
$C_8H_8O_3$	*m*-Methoxybenzoic acid	25	0.004–0.0002	381	8.8×10^{-5}	(457)
$C_8H_8O_3$	*p*-Methoxybenzoic acid	25	0.002–0.0005	381	3.1×10^{-5}	(436)
					3.6×10^{-5}	(457)
		0–99	0.004–0.0005			(506, 526)
$C_8H_8O_3$	Orcyl aldehyde	25	0.001–0.0001	380	4.00×10^{-5}	(204)
$C_8H_8O_3$	Phenoxyacetic acid	25	0.03–0.001	380	7.4×10^{-4}	(436, 536)
$C_8H_8O_3$	*d*-Phenylglycolic acid	25	0.5–0.001	379	4.3×10^{-4}	(73)
$C_8H_8O_3$	*l*-Phenylglycolic acid	25	(?)	(?)	4.2×10^{-4}	(570)
$C_8H_8O_3$	*dl*-Phenylglycolic acid	25	1.0–0.001	379	4.09×10^{-4}	(376, 436)
					4.3×10^{-4}	(73); *cf.* (570)
		0–65	0.12–0.0005			(525, 609)
$C_8H_8O_3$	Vanillin	25	0.008–0.001	380	4.72×10^{-6}	(204)
$C_8H_8O_4$	Dehydroacetic acid	25	0.01–0.001	379	5.3×10^{-6}	(436)
					1×10^{-6}	(129)
$C_8H_8O_4$	Isodehydroacetic acid	25	0.03–0.001	378	5.3×10^{-3}	(378, 436)
$C_8H_8O_4$	$\Delta^{1,3}$-Dihydrophthalic acid	25	0.03–0.0001	380	7×10^{-4}	(1)
$C_8H_8O_4$	$\Delta^{2,4}$-Dihydrophthalic acid	25	(?)	379	1.55×10^{-4}	(27)
$C_8H_8O_4$	$\Delta^{2,5}$-Dihydrophthalic acid	25	0.03–0.001	379	5.45×10^{-4}	(2)
$C_8H_8O_4$	$\Delta^{2,6}$-Dihydrophthalic acid	25	0.016–0.001	379	1.62×10^{-4}	(524); *cf.* (28)
$C_8H_8O_4$	*trans*-$\Delta^{3,5}$-Dihydrophthalic acid	25	(?)	379	2.46×10^{-4}	(27)
$C_8H_8O_4$	Dimethylpyronecarboxylic acid	25	0.02–0.003	378	3.85×10^{-4}	(181)
$C_8H_8O_4$	Guaiacolcarboxylic acid	25	0.016–0.001	380	1.35×10^{-3}	(323, 378)
$C_8H_8O_4$	Orsellic acid	25	0.008–0.001	380	1.3×10^{-4}	(260)
$C_8H_8O_4$	*p*-Orsellic acid	25	0.008–0.001	380	3.8×10^{-2}	(260, 436)
$C_8H_8O_4$	2-Methylpyrone-6-acetic acid	(?)	(?)	(?)	1.52×10^{-5}	(130)
$C_8H_8O_4$	Vanillic acid	25	0.016–0.001	380	2.94×10^{-5}	(436); *cf.* (378)
		0–65	0.004–0.0005			(526)
$C_8H_8O_4$	Isovanillic acid	25	0.004–0.001	380	3.1×10^{-5}	(436)
$C_8H_8O_5$	Methyl gallate	25	0.03–0.004	377	9×10^{-8}	(135)
$C_8H_8O_5$	Hematinic acid anhydride	25	0.05–0.0008	379	2.25×10^{-4}	(333)
$C_8H_8O_5$	Hydroxydehydroacetic acid	25	0.002–0.0004	380	1.6×10^{-3}	(182)
$C_8H_8O_5S$	α-Monomethyl *m*-sulfobenzoate	25	0.004–0.003	377	7×10^{-4}	(598)
$C_8H_8O_5S$	α-Monomethyl *p*-sulfobenzoate	25	0.0009	380	$[7.2 \times 10^{-4}]$	(601)
$C_8H_8O_5S$	β-Monomethyl *m*-sulfobenzoate	25	0.02–0.0007	377	$\Lambda_{0.02} = 345$	(598)
C_8H_9NO	Acetophenoneoxime	25	0.008–0.001	380	3.7×10^{-9}	(557); *cf.* (226)
$C_8H_9NO_2$	*o*-Methylaminobenzoic acid	25	0.0013–0.0007	380	4.5×10^{-6}	(140)
$C_8H_9NO_2$	*m*-Methylaminobenzoic acid	25	0.012–0.0008	379	7×10^{-6}	(140)
$C_8H_9NO_2$	*p*-Methylaminobenzoic acid	25	0.008–0.001	379	9.0×10^{-6}	(297)
$C_8H_9NO_2$	Phenylaminoacetic acid	25	0.03–0.001	378	3.8×10^{-5}	(436, 579)
$C_8H_9NO_3$	Anishydroxamic acid	25	0.008–0.002	380	7.3×10^{-7}	(426)
$C_8H_9NO_4$	2, 4-Dimethylpyrrole-3, 5-dicarboxylic acid	25	0.0008–0.0004	380	2.0×10^{-5}	(7)
$C_8H_9NO_4$	2, 5-Dimethylpyrrole-3, 4-dicarboxylic acid	25	0.0008–0.0002	378	$\Lambda_{0.0008} = 345$	(7)
$C_8H_9NO_4$	Hematinic imide	25	0.05–0.0008	376	$[3.63 \times 10^{-5}]$	(333); *cf.* (336)
$C_8H_9NO_4S$	Benzenesulfoneaminoacetic acid	25	0.016–0.001	376	3.46×10^{-4}	(358)
$C_8H_{10}N_2O$	*O*-Methyl-*N*-phenylpseudourea	25	0.12–0.004	226	2.5×10^{-7}	(107)
$C_8H_{10}N_2O_5S$	Nitrodimethylanilinesulfonic acid	25	0.03–0.001	379	$\Lambda_{0.03} = 88.4$	(165)
$C_8H_{10}N_4O_2$	Caffeine	25	0.05–0.02	(?)	$\Lambda_{0.05} = 0.15$	(392)
$C_8H_{10}O$	1, 3-Dimethyl-4-hydroxybenzene	25	0.014–0.004	381	3×10^{-8}	(26)
$C_8H_{10}O_3S$	*p*-Tolubenzylsulfonic acid	25	0.12–0.001	376	$\Lambda_{0.03} = 356$	(143)
$C_8H_{10}O_3S$	1, 4-Xylene-2-sulfonic acid	25	0.12–0.001	376	$\Lambda_{0.03} = 362$	(143)
$C_8H_{10}O_4$	β-Mesityloxide oxalic acid	(?)	(?)	(?)	1×10^{-2}	(155)
$C_8H_{10}O_4$	*trans*-Δ^1-Tetrahydrophthalic acid	25	(?)	379	5.9×10^{-4}	(27)
$C_8H_{10}O_4$	Δ^1-Tetrahydroterephthalic acid	25	0.003–0.0004	378	5.0×10^{-5}	(524)

℃-Table.—The ℃-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_8H_{10}O_4$	Δ^2-Tetrahydrophthalic acid	25	0.016–0.001	378	7.4×10^{-5}	(524); *cf.* (28)
$C_8H_{10}O_4$	Δ^3-Tetrahydrophthalic acid	25	0.03–0.0001	380	5.70×10^{-4}	(1)
$C_8H_{10}O_4$	*cis*-Δ^4-Tetrahydrophthalic acid	25	(?)	379	6.2×10^{-4}	(3)
$C_8H_{10}O_4$	*trans*-Δ^4-Tetrahydrophthalic acid	25	(?)	379	1.18×10^{-4}	(27)
					1.30×10^{-4}	(3)
$C_8H_{10}O_8$	α-Butanetetracarboxylic acid	25	0.03–0.001	376	3.95×10^{-4}	(292, 578)
$C_8H_{10}O_8$	β-Butanetetracarboxylic acid	25	0.03–0.002	376	4.1×10^{-4}	(23, 292)
					8×10^{-4}	(578)
$C_8H_{10}O_8$	Diacetyltartaric acid	25	0.85–0.001	379	$\Lambda_{0.03} = 229$	(147, 577)
$C_8H_{11}N$	2, 4, 6-Trimethylpyridine	10	0.10–0.007	171	1.22×10^{-7}	(363)
		15	0.10–0.007	191	1.42×10^{-7}	(363)
		25	0.10–0.007	229	2.05×10^{-7}	(363)
		25	0.11–0.014			(207)
		40	0.10–0.007	290	3.05×10^{-7}	(363)
		50	0.10–0.007	330	3.75×10^{-7}	(363)
$C_8H_{11}NO_3$	Propyl cyanoacetoacetate	25	0.008–0.001	378	5.7×10^{-4}	(214)
$C_8H_{11}NO_3$	Methyl cyanobutyrylacetate	25	0.008–0.001	377	6.1×10^{-4}	(214)
$C_8H_{11}NO_3$	Methyl cyanoisobutyrylacetate	25	0.002–0.001	377	4.9×10^{-4}	(214)
$C_8H_{11}NO_3$	Dimethylviolanic acid	25	0.03–0.004	378	3.94×10^{-6}	(348)
$C_8H_{11}NO_3S$	Dimethylaniline-4-sulfonic acid	25	0.06–0.002	376	3.68×10^{-4}	(165)
$C_8H_{11}NO_3S$	Ethylaniline-3-sulfonic acid	25	0.03–0.001	379	1.59×10^{-4}	(205)
$C_8H_{11}NO_3S$	Ethylaniline-4-sulfonic acid	25	0.03–0.001	379	1.25×10^{-4}	(205)
$C_8H_{11}NO_3S$	1, 4, 2-Xylidine-5-sulfonic acid	25	0.016–0.001	379	4.32×10^{-4}	(436)
$C_8H_{11}NO_4$	Diethyl cyanomalonate	25	0.016–0.0005	376	$\Lambda_{0.016} = 283$	(213)
$C_8H_{12}N_2$	Dimethyl-*p*-phenylenediamine	25	0.08	(?)	$\Lambda_{0.08} > 0.19$	(230)
$C_8H_{12}N_2O_3$	5, 5-Diethylbarbituric acid	25	0.016	378	3.7×10^{-8}	(624)
$C_8H_{12}O_2$	1-Cycloheptene-1-carboxylic acid	25	0.004–0.001	379	9.8×10^{-6}	(486)
					8.2×10^{-6}	(616)
$C_8H_{12}O_2$	2-Cycloheptene-1-carboxylic acid	25	0.016–0.002	379	2.60×10^{-5}	(486)
$C_8H_{12}O_2$	Cyclohexeneacetic acid (liquid isomer)	25	0.02–0.001	378	2.55×10^{-5}	(635)
$C_8H_{12}O_2$	Cyclohexeneacetic acid (solid isomer)	25	0.02–0.001	378	2.45×10^{-5}	(635)
$C_8H_{12}O_2$	Dimethyldihydroresorcinol	25	0.016–0.001	377	7.1×10^{-6}	(508)
$C_8H_{12}O_3$	Heptic acid	25	0.008–0.002	376	8.2×10^{-5}	(569)
$C_8H_{12}O_4$	Isobutylfumaric acid	25	0.008–0.001	378	9.1×10^{-4}	(577)
$C_8H_{12}O_4$	Ethyl diacetoacetate	25	0.008	(?)	$[\Lambda_{0.008} = 3.5]$	(213)
$C_8H_{12}O_4$	Dicrotonic acid	25	(?)	(?)	2.8×10^{-5}	(443)
$C_8H_{12}O_4$	*cis*-Hexahydrophthalic acid	25	(?)	378	4.4×10^{-5}	(27)
$C_8H_{12}O_4$	*trans*-Hexahydrophthalic acid	25	(?)	378	6.2×10^{-5}	(27)
$C_8H_{12}O_4$	*cis*-Hexahydroterephthalic acid	25	0.015–0.0005	377	2.91×10^{-5}	(524)
$C_8H_{12}O_4$	*trans*-Hexahydroterephthalic acid	25	0.005–0.0006	377	4.48×10^{-5}	(524)
$C_8H_{12}O_4$	*meso*-Methylallylsuccinic acid	25	0.06–0.0005	377	2.28×10^{-4}	(268)
$C_8H_{12}O_4$	*p*-Methylallylsuccinic acid	25	0.06–0.0005	377	2.40×10^{-4}	(268)
$C_8H_{12}O_4$	γ-Methyl-γ-ethylidenepyrotartaric acid	25	0.02–0.0007	376	1.10×10^{-4}	(530)
$C_8H_{12}O_4$	Methylethylitaconic acid	25	0.007–0.0005	377	1.47×10^{-4}	(524)
$C_8H_{12}O_4$	Methylpropylmaleic acid	25	0.016–0.001	379	7.2×10^{-5}	(335)
$C_8H_{12}O_4$	Methylisopropylmaleic acid	25	0.016–0.001	379	1.5×10^{-4}	(335)
$C_8H_{12}O_6$	α, α-Dimethyltricarballylic acid	25	0.04–0.005	375	3.15×10^{-4}	(98)
$C_8H_{12}O_6$	α, α'-Dimethyltricarballylic acid (*a* acid, M. P. 206–7°)	25	0.03–0.004	377	4.3×10^{-4}	(98, 630)
$C_8H_{12}O_6$	α, α'-Dimethyltricarballylic acid (*b* acid, M. P., 174°)	25	0.05–0.006	377	5.4×10^{-4}	(98, 630)
$C_8H_{12}O_6$	α, α'-Dimethyltricarballylic acid (*c* acid, M. P., 148°)	25	0.05–0.006	377	5.6×10^{-4}	(98)
					5.1×10^{-4}	(630)
$C_8H_{12}O_6$	Ethyltricarballylic acid	25	0.03–0.001	376	3.1×10^{-4}	(578)
$C_8H_{12}O_6$	Hemotricarboxylic acid:					
	(*a*) M. P., 140–141°	25	0.03–0.001	378	$[2.48 \times 10^{-4}]$	(334, 337)
	(*b*) M. P., 175–176°	25	0.03–0.001	378	$[2.44 \times 10^{-4}]$	(334, 337)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_8H_{13}NO_4$	Tropic acid	25	0.03–0.001	377	4.2×10^{-4}	(618)
$C_8H_{14}O_2$	Cycloheptanecarboxylic acid	25	0.004–0.001	378	1.20×10^{-5}	(635)
$C_8H_{14}O_2$	Cyclohexaneacetic acid	25	0.005–0.0009	378	2.32×10^{-5}	(635)
$C_8H_{14}O_2$	1-Ethylpentamethylene-2-carboxylic acid	25	0.015–0.001	378	1.09×10^{-5}	(635)
$C_8H_{14}O_2$	1-Methylcyclohexane-1-carboxylic acid	25	0.008–0.001	378	6.8×10^{-6}	(635)
$C_8H_{14}O_2$	*cis*-1-Methylcyclohexane-2-carboxylic acid	25	0.005–0.0006	378	1.61×10^{-5}	(635)
$C_8H_{14}O_2$	*trans*-1-Methylcyclohexane-2-carboxylic acid	25	0.02–0.0006	378	2.01×10^{-5}	(635)
$C_8H_{14}O_2$	1-Methylcyclohexane-3-carboxylic acid	25	0.02–0.001	378	1.26×10^{-5}	(635)
$C_8H_{14}O_2$	1-Methylcyclohexane-4-carboxylic acid	25	0.005–0.0006	378	1.09×10^{-5}	(635)
$C_8H_{14}O_3$	Ethyl ethylacetoacetate	25	0.008–0.004	(?)	$\Lambda_{0.008} = 0.07$	(569)
$C_8H_{14}O_4$	Monoethyl adipate	25	0.01–0.0007	375	2.5×10^{-5}	(582)
$C_8H_{14}O_4$	Isoamylmalonic acid	25	0.06–0.001	377	1.22×10^{-3}	(390)
$C_8H_{14}O_4$	Isobutylsuccinic acid	25	0.03–0.001	377	8.65×10^{-5}	(569, 577)
$C_8H_{14}O_4$	Diethylsuccinic acid	25	0.03–0.001	377	3.79×10^{-4}	(577)
$C_8H_{14}O_4$	*fum.-sym.*-Diethylsuccinic acid	25	0.03–0.001	377	2.32×10^{-4}	(139, 577, 631)
$C_8H_{14}O_4$	*mal.-sym.*-Diethylsuccinic acid	25	0.03–0.0007	377	3.41×10^{-4}	(139, 577, 631)
$C_8H_{14}O_4$	*α-sym.*-Dimethyladipic acid	25	0.02–0.002	377	4.1×10^{-5}	(631)
$C_8H_{14}O_4$	*β-sym.*-Dimethyladipic acid	25	0.04–0.003	377	4.1×10^{-5}	(631)
$C_8H_{14}O_4$	Dimethylethylsuccinic acid	25	0.03–0.001	377	5.50×10^{-4}	(97, 577)
$C_8H_{14}O_4$	Dimethyl-*H*-ethylsuccinic acid	25	0.03–0.002	376	5.7×10^{-5}	(60)
$C_8H_{14}O_4$	*α*-Ethyladipic acid	24.2	0.02–0.0013	374	4.0×10^{-5}	(391)
$C_8H_{14}O_4$	Ethylpropylmalonic acid	25	0.06–0.001	375	8.9×10^{-3}	(390, 535)
$C_8H_{14}O_4$	Ethylisopropylmalonic acid	25	0.03–0.001	375	1.05×10^{-2}	(390)
$C_8H_{14}O_4$	Methylbutylmalonic acid	25	0.06–0.001	375	1.80×10^{-3}	(390)
$C_8H_{14}O_4$	Methylisobutylmalonic acid	25	0.03–0.001	375	3.0×10^{-3}	(390)
$C_8H_{14}O_4$	*meso-α*-Methyl-*α'*-ethylglutaric acid	25	0.03–0.001	377	5.5×10^{-5}	(60, 577)
$C_8H_{14}O_4$	*β*-Methyl-*α*-ethylglutaric acid	(?)	(?)	(?)	6.7×10^{-5}	(443)
$C_8H_{14}O_4$	*β*-Methyl-*β*-ethylglutaric acid	25	0.03–0.001	(?)	2.44×10^{-4}	(525.2)
$C_8H_{14}O_4$	*α*-Methylpimelic acid	(?)	(?)	(?)	3.15×10^{-5}	(633)
$C_8H_{14}O_4$	*cis-sym.*-Methylisopropylsuccinic acid	25	0.01–0.0014	375	6.6×10^{-4}	(96)
$C_8H_{14}O_4$	*trans-sym.*-Methylisopropylsuccinic acid	25	0.006–0.0008	375	1.56×10^{-4}	(96)
$C_8H_{14}O_4$	*cis-α, α'*-Methylpropylsuccinic acid	25	0.008–0.001	375	2.95×10^{-4}	(96)
$C_8H_{14}O_4$	*trans-α, α'*-Methylpropylsuccinic acid	25	0.004–0.0005	375	1.45×10^{-4}	(96)
$C_8H_{14}O_4$	*α*-Propylglutaric acid	24.4	0.016–0.001	375	5.8×10^{-5}	(391)
$C_8H_{14}O_4$	*α*-Isopropylglutaric acid	25	0.05–0.0009	377	5.40×10^{-5}	(8, 391)
$C_8H_{14}O_4$	*β*-Isopropylglutaric acid	[25]	(?)	(?)	6.46×10^{-4}	(289)
$C_8H_{14}O_4$	Suberic acid	25	0.016–0.0005	377	2.96×10^{-5}	(49, 138, 524, 565); *cf.* (59, 436)
$C_8H_{14}O_4$	Tetramethylsuccinic acid	25	0.012–0.0005	376	3.08×10^{-4}	(49, 61, 139, 561)
$C_8H_{14}O_4$	Monomethyl trimethylsuccinate	25	0.06–0.007	375	2.65×10^{-5}	(100)
$C_8H_{14}O_4$	*α, α, α'*-Trimethylglutaric acid	25	0.01–0.0007	376	3.4×10^{-5}	(49, 61)
$C_8H_{14}O_4$	*α, β, β*-Trimethylglutaric acid	25	0.03–0.001	377	1.44×10^{-4}	(30)
$C_8H_{14}O_6$	*α*-Dimethyldihydroxyadipic acid	(?)	(?)	(?)	3.17×10^{-4}	(634)
$C_8H_{14}O_6$	*γ*-Dimethyldihydroxyadipic acid	(?)	(?)	(?)	3.30×10^{-4}	(634)
$C_8H_{15}NO$	Tropine	10	0.06–0.01	170	1.87×10^{-4}	(365)
		25	0.06–0.01	227	2.74×10^{-4}	(365)
		50	0.06–0.01	326	3.89×10^{-4}	(365)
$C_8H_{16}O_2$	Caprylic acid	25	0.004–0.001	377	1.41×10^{-5}	(200)
		0–65	0.002–0.0005			(610, 611)
$C_8H_{16}O_3$	Diisopropylglycolic acid	25	0.03–0.001	376	1.27×10^{-4}	(550)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_8H_{16}O_3$	α-Dimethyl-β-isopropylethylene-lactic acid	25	0.03–0.0009	376	2.16×10^{-5}	(550)
$C_8H_{16}O_3$	α-Hydroxycaprylic acid	25	0.008–0.0005	377	1.55×10^{-4}	(88)
$C_8H_{17}N$	*d*-Coniine	25	0.06–0.004	226	1.05×10^{-3}	(104, 392, 629
$C_8H_{19}N$	Diisobutylamine	25	0.016–0.004	225	3.9×10^{-4}	(104)
$C_8H_{21}NO$	Tetraethylammonium hydroxide	25	0.06–0.004	230	$\Lambda_{0.06} = 188$	(433)
$C_9H_5NO_3$	Isonitrosodiketohydrindene	25	0.006–0.001	378	1.8×10^{-6}	(235)
					1.0×10^{-6}	(379)
$C_9H_5NO_4$	*o*-Nitrophenylpropiolic acid	25	0.004–0.001	376	1.01×10^{-2}	(436)
$C_9H_5NO_8$	Pyridine-2, 3, 4, 5-tetracarboxylic acid	25	0.004–0.0002	(?)	$\Lambda_{0.004} = 497$	(436)
$C_9H_6N_2O_2$	Benzoylpseudo-α, β'-furazane	25	0.005–0.001	378	3.2×10^{-2}	(80)
$C_9H_6N_2O_3$	Phenylazoxazolecarboxylic acid	25	0.016–0.002	376	3×10^{-2}	(244)
$C_9H_6N_2O_3$	Phenyloximino-*syn*-oxazolone	25	0.002–0.001	376	1.85×10^{-4}	(244)
$C_9H_6O_2$	Phenylpropiolic acid	25	0.016–0.001	378	5.8×10^{-3}	(436)
		0–65	0.008–0.0005			(526)
$C_9H_6O_5$	Phthalonic acid	25	0.20–0.001	378	2.5×10^{-2}	(69, 540)
$C_9H_6O_6$	Trimellitic acid	25	0.03–0.001	378	3.2×10^{-3}	(601)
$C_9H_6O_6$	Trimesic acid	25	0.02–0.0006	378	$\Lambda_{0.009} = 91.0$	(49)
$C_9H_7BrO_2$	α-Bromocinnamic acid	25	0.002–0.0005	378	9.1×10^{-4}	(436)
$C_9H_7BrO_2$	β-Bromocinnamic acid	25	0.009–0.001	378	1.4×10^{-2}	(436)
		25–99	0.008–0.001			(506)
$C_9H_7BrO_4$	1-Monomethyl 2-bromoterephthalate	25	0.002–0.0005	378	3.7×10^{-4}	(598)
$C_9H_7BrO_4$	4-Monomethyl 2-bromoterephthalate	25	0.004–0.001	378	5×10^{-3}	(598)
$C_9H_7Br_2FO_2$	α, β-Dibromo-α-fluorohydrocinnamic acid	25	0.016–0.002	374	$\Lambda_{0.016} = 347.7$	(546)
$C_9H_7ClO_2$	β-Chloroallocinnamic acid	25	0.0014–0.0007	377	2.8×10^{-4}	(412)
$C_9H_7ClO_2$	β-Chlorocinnamic acid	25	0.003–0.0007	377	2.7×10^{-4}	(412)
$C_9H_7ClO_2$	1′-Chlorocinnamic acid	25	0.005–0.0012	377	1.1×10^{-2}	(412)
$C_9H_7ClO_2$	1²-Chlorocinnamic acid	25	0.004–0.0005	377	1.0×10^{-3}	(412)
$C_9H_7FO_2$	α-Fluorocinnamic acid	25	0.004–0.001	375	1.9×10^{-3}	(546)
$C_9H_7IO_2$	α-Iodoallocinnamic acid	[25]	0.001–0.0006	377	5.8×10^{-6}	(294)
$C_9H_7IO_2$	β-Iodoallocinnamic acid	[25]	0.0004	377	2.3×10^{-6}	(294)
$C_9H_7IO_2$	α-Iodocinnamic acid	[25]	0.0009–0.0004	377	5.0×10^{-6}	(294)
$C_9H_7IO_2$	β-Iodocinnamic acid	[25]	0.001–0.0007	377	4.0×10^{-6}	(294)
$C_9H_7NO_2$	*Pr*-2-(α)-Indolecarboxylic acid	25	0.006–0.0007	377	1.74×10^{-4}	(7)
$C_9H_7NO_2$	*Pr*-3-(β)-Indolecarboxylic acid	25	0.0014–0.0004	377	5.4×10^{-6}	(7)
$C_9H_7NO_2$	Phenyl-*syn*-oxazolone	25	0.002–0.001	378	5.3×10^{-5}	(244)
$C_9H_7NO_3$	2, 3, 4-Trihydroxyquinoline	25	0.0008	(?)	$\Lambda_{0.0008} = 2.1$	(569)
$C_9H_7NO_5$	1-Trimellitamic acid	25	0.03–0.0005	378	4.4×10^{-4}	(601)
$C_9H_7NO_5$	2-Trimellitamic acid	25	0.03–0.0005	378	7.5×10^{-4}	(601)
$C_9H_7NO_5S$	*o*-Benzoylsulfoglycine	25	0.03–0.001	(?)	[$\Lambda_{0.03} = 0.09$]	(374)
$C_9H_7NO_5S$	Mono-(*C*)-methyl sulfimidephthalate	25	0.025	375	3.1×10^{-2}	(637)
$C_9H_7NO_5S$	Mono-(*N*)-methyl sulfimidephthalate	25	0.025	375	3.8×10^{-3}	(637)
$C_9H_7NO_6$	2-Methylpyridine-3, 5, 6-tricarboxylic acid	25	0.008–0.0002	(?)	$\Lambda_{0.008} = 298$	(436)
$C_9H_7NO_6$	4-Methylpyridine-3, 5, 6-tricarboxylic acid	25	0.008–0.0002	(?)	$\Lambda_{0.008} = 365$	(436)
$C_9H_7NO_6$	1-Monomethyl 2-nitroterephthalate	25	0.004–0.001	377	7.6×10^{-4}	(598)
$C_9H_7NO_6$	4-Monomethyl 2-nitroterephthalate	25	0.016–0.001	377	1.9×10^{-2}	(598)
$C_9H_7NO_6$	1-Monomethyl 3-nitrophthalate	25	0.016–0.001	377	1.6×10^{-2}	(598)
$C_9H_7NO_6$	2-Monomethyl 3-nitrophthalate	25	0.008–0.001	377	2.0×10^{-3}	(598)
$C_9H_7NO_6$	1-Monomethyl 4-nitroisophthalate	25	0.004–0.001	377	1.05×10^{-2}	(601)
$C_9H_7NO_6$	3-Monomethyl 4-nitroisophthalate	25	0.002–0.0005	377	8.3×10^{-4}	(601)
$C_9H_7NO_6$	?-Monomethyl 4-nitrophthalate	25	0.016–0.001	377	4.6×10^{-3}	(598)
$C_9H_7N_3O_2$	*C*-Phenylosotriazolecarboxylic acid	20	0.004	(?)	$\Lambda_{0.004} = 94.9$	(429)
		0–40	0.004			(429)
$C_9H_8BrClO_5$	Ethyl 2-chloro-6-bromogallate	25	0.03–0.004	373	2×10^{-6}	(135)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_9H_8Br_2O_5$	Ethyl dibromogallate	25	0.016–0.002	374	1.5×10^{-6}	(135)
$C_9H_8Cl_2O_4$	Dichloroveratric acid	25	0.001–0.0002	376	$[1 \times 10^{-3}]$	(135)
$C_9H_8Cl_2O_5$	Ethyl 2, 6-dichlorogallate	25	0.03–0.004	374	4.1×10^{-7}	(135)
$C_9H_8N_2O_2$	*m*-Methyl-α-benzimideazolecarboxylic acid	[25]	0.005–0.0013	(?)	1.07×10^{-6}	(33)
$C_9H_8N_2O_2$	α-Methyl-*m*-benzimideazolecarboxylic acid	25	0.0014–0.0007	375	1.00×10^{-6}	(26)
$C_9H_8N_2O_4$	Phthaluric acid	25	0.016–0.001	376	2.84×10^{-4}	(436)
$C_9H_8N_2O_8$	2, 3-Dimethoxy-5, 6-dinitrobenzoic acid	25	0.004–0.001	376	4.4×10^{-2}	(601)
$C_9H_8O_2$	Atropic acid	25	0.008–0.0005	378	1.40×10^{-4}	(436)
$C_9H_8O_2$	Cinnamic acid	25	0.004–0.0004	378	3.51×10^{-5}	(169, 436)
					3.65×10^{-5}	(488)
		0–99	0.002–0.0005			(506, 526, 609)
$C_9H_8O_2$	Allocinnamic acid (M. P., 68°)	25	0.02–0.001	378	1.39×10^{-4}	(51, 347); *cf.* (399, 488)
$C_9H_8O_2$	Isocinnamic acid (M. P., 42°)	25	0.02–0.001	378	1.35×10^{-4}	(51, 345, 396, 399)
$C_9H_8O_2$	Isocinnamic acid (M. P., 58°)	25	0.02–0.001	378	1.38×10^{-4}	(51, 399); *cf.* (26, 436)
$C_9H_8O_2$	*hetero*-α-Cinnamic acid	25	0.003–0.0004	378	3.5×10^{-5}	(168)
$C_9H_8O_2$	*hetero*-β-Cinnamic acid	25	0.003–0.0004	378	3.53×10^{-5}	(168)
$C_9H_8O_2$	*storax*-α-Cinnamic acid	25	0.003–0.0008	378	3.56×10^{-5}	(168)
$C_9H_8O_2$	*storax*-β-Cinnamic acid	25	0.004–0.0004	378	3.6×10^{-5}	(168)
$C_9H_8O_3$	*o*-Coumaric acid	25	0.004–0.001	378	2.4×10^{-5}	(378); *cf.* (436)
		0–65	0.004–0.0005			(526)
$C_9H_8O_3$	*allo*-*p*-Coumaric acid	25	0.024–0.002	378	8.0×10^{-5}	(488)
$C_9H_8O_3$	*p*-Coumaric acid	25	0.008–0.001	378	2.14×10^{-5}	(436)
					2.25×10^{-5}	(488)
$C_9H_8O_4$	*o*-Acetoxybenzoic acid	25	0.016–0.001	377	3.3×10^{-4}	(436)
		0–50	0.008–0.0005			(526)
$C_9H_8O_4$	*m*-Acetoxybenzoic acid	25	0.004–0.001	377	9.68×10^{-5}	(436)
		0–35	0.008–0.0005			(525)
$C_9H_8O_4$	*p*-Acetoxybenzoic acid	25	0.016–0.001	377	4.15×10^{-5}	(436)
$C_9H_8O_4$	Homophthalic acid	25	0.03–0.001	378	1.88×10^{-4}	(156, 540)
$C_9H_8O_4$	Monomethyl phthalate	25	0.01–0.0012	377	6.55×10^{-4}	(582)
$C_9H_8O_4$	Monomethylisophthalate	25	0.002–0.0005	378	1.28×10^{-4}	(601)
$C_9H_8O_4$	Umbellic acid	25	0.008–0.001	378	1.85×10^{-5}	(436)
$C_9H_8O_4$	*sym.*-Uvitic acid	25	0.004–0.0005	378	3.0×10^{-4}	(49)
$C_9H_8O_5$	1-Monomethyl 4-hydroxyphthalate	25	0.01–0.0007	377	1.52×10^{-4}	(601)
$C_9H_8O_5$	2-Monomethyl 4-hydroxyphthalate	25	0.016–0.001	377	2.02×10^{-4}	(598)
$C_9H_8O_5$	1-Monomethyl 2-hydroxyterephthalate	25	0.001–0.0005	377	2.50×10^{-4}	(598)
$C_9H_8O_5$	4-Monomethyl 2-hydroxyterephthalate	25	0.004–0.001	377	2.7×10^{-3}	(598)
$C_9H_8O_5$	4-Methoxyisophthalic acid	25	0.002–0.0005	378	2.6×10^{-4}	(457)
$C_9H_8O_6$	Carboxydehydroacetic acid	25	0.006–0.0016	376	$\Lambda_{0.006} = 320$	(444)
$C_9H_9BrO_2$	β-Phenyl-α-bromopropionic acid	25	0.01–0.0005	378	1.67×10^{-3}	(514)
$C_9H_9ClO_3$	α-Chloro-β-hydroxyphenylpropionic acid	25	0.06–0.001	376	2.40×10^{-3}	(523)
$C_9H_9ClO_3$	2-Ethoxy-5-chlorobenzoic acid	25	0.0011–0.0003	376	1.31×10^{-4}	(135)
$C_9H_9ClO_5$	Ethyl 2-chlorogallate	25	0.04–0.005	375	1.8×10^{-7}	(135)
$C_9H_9NO_3$	*o*-Acetylaminobenzoic acid	25	0.008–0.001	376	2.31×10^{-4}	(436)
$C_9H_9NO_3$	*m*-Acetylaminobenzoic acid	25	0.004–0.001	376	8.4×10^{-5}	(436)
$C_9H_9NO_3$	*p*-Acetylaminobenzoic acid	25	0.004–0.001	376	5.07×10^{-5}	(436)
$C_9H_9NO_3$	Benzoylaminoacetic acid	25	0.03–0.001	376	2.16×10^{-4}	(378, 436, 622)
		0–65	0.008–0.0005			(525, 609)
$C_9H_9NO_3$	1-Homophthalamic acid	25	0.002–0.001	378	5.0×10^{-5}	(540)
$C_9H_9NO_3$	2-Homophthalamic acid	25	0.004–0.001	378	8.7×10^{-5}	(540)
$C_9H_9NO_3$	Malonanilic acid	25	0.016–0.001	376	1.92×10^{-4}	(436)
$C_9H_9NO_3$	α-Oximino-β-phenylpropionic acid	25	0.03–0.004	377	5.9×10^{-4}	(265)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_9H_9NO_3$	*p*-Tolyloxamic acid	25	0.008–0.001	376	8.3×10^{-3}	(436)
$C_9H_9NO_4$	1-Monomethyl 2-aminoterephthalate	25	0.001–0.0005	377	1.5×10^{-4}	(601)
$C_9H_9NO_4$	4-Monomethyl 2-aminoterephthalate	25	0.002–0.001	378	5.46×10^{-5}	(540)
$C_9H_9NO_4$	1-Monomethyl 4-aminoisophthalate	25	0.001–0.0005	377	4.4×10^{-5}	(601)
$C_9H_9NO_4$	3-Monomethyl 4-aminoisophthalate	25	0.001–0.0005	377	2.65×10^{-5}	(601)
$C_9H_9NO_4$	α, α'-Dimethylcinchomeronic acid	25	0.012–0.0007	378	1.65×10^{-3}	(413)
$C_9H_9NO_4$	2, 4-Dimethylpyridine-3, 5-dicarboxylic acid	25	0.008–0.002	378	5.0×10^{-3}	(436)
$C_9H_9NO_4$	2, 6-Dimethylpyridine-3, 5-dicarboxylic acid	25	0.008–0.001	378	3.4×10^{-3}	(436)
$C_9H_9NO_4$	2-*N*-Methylaminoterephthalic acid	25	0.0016–0.0003	377	2.8×10^{-4}	(540, 601)
$C_9H_9NO_4$	Phenylglycine-*o*-carboxylic acid	25	0.007–0.0005	377	2.25×10^{-4}	(394)
$C_9H_9NO_4$	Monoethyl pyridine-3, 4-dicarboxylate	25	0.06–0.0008	378	4.8×10^{-4}	(49)
$C_9H_9NO_6$	2-Nitro-3, 4-dimethoxybenzoic acid	25	0.0025–0.0006	376	7.9×10^{-4}	(323)
$C_9H_9NO_6$	3-Nitro-2, 5-dimethoxybenzoic acid	25	0.0016–0.0008	376	1.7×10^{-3}	(323)
$C_9H_9NO_6$	6-Nitro-2, 3-dimethoxybenzoic acid	25	0.01–0.0006	376	$\Lambda_{0.01} = 237.3$	(323)
$C_9H_9NO_6$	6-Nitroveratric acid	25	0.008–0.002	376	3.2×10^{-3}	(49)
$C_9H_9N_3OS$	4-Methyl-1-phenyl-3-thiourazole	25	0.004–0.002	378	[$\Lambda_{0.004} = 319$]	(6)
$C_9H_9N_3OS$	1-Phenyl-3-methylthiourazole	25	0.001–0.00025	378	1.2×10^{-7}	(6)
$C_9H_9N_3O_2$	2-Methyl-1-phenylurazole	25	0.008–0.001	378	6.6×10^{-8}	(6)
$C_9H_9N_3O_2$	4-Methyl-1-phenylurazole	25	0.002–0.0005	378	1.2×10^{-5}	(6)
$C_9H_{10}O_2$	2, 4-Dimethylbenzoic acid	25	0.001–0.0005	378	9×10^{-5}	(451)
$C_9H_{10}O_2$	2, 5-Dimethylbenzoic acid	25	0.002–0.001	378	1.2×10^{-4}	(451)
$C_9H_{10}O_2$	2, 6-Dimethylbenzoic acid	25	0.008–0.001	379	6.2×10^{-4}	(290)
$C_9H_{10}O_2$	3, 5-Dimethylbenzoic acid	25	0.0012–0.0005	379	4.7×10^{-5}	(49)
					7.1×10^{-5}	(451)
$C_9H_{10}O_2$	*o*-Ethylbenzoic acid	25	0.004–0.001	379	1.7×10^{-4}	(451)
$C_9H_{10}O_2$	Hydratropic acid	25	0.016–0.001	378	4.16×10^{-5}	(436)
$C_9H_{10}O_2$	Hydrocinnamic acid	25	0.016–0.001	378	2.23×10^{-5}	(436)
		0–65	0.03–0.0005			(526)
$C_9H_{10}O_3$	*o*-Ethoxybenzoic acid	25	0.008–0.002	378	7.0×10^{-5}	(457)
$C_9H_{10}O_3$	*m*-Ethoxybenzoic acid	25	0.002–0.0002	378	9.0×10^{-5}	(457)
$C_9H_{10}O_3$	*p*-Ethoxybenzoic acid	25	0.0005–0.0002	378	5.0×10^{-5}	(457)
$C_9H_{10}O_3$	*p*-Hydrocoumaric acid	25	0.008–0.001	378	1.71×10^{-5}	(436)
$C_9H_{10}O_3$	4-Methoxy-*m*-toluic acid	25	0.008–0.0005	378	6.65×10^{-5}	(457)
$C_9H_{10}O_3$	6-Methoxy-*m*-toluic acid	25	0.0005–0.0002	378	3.4×10^{-5}	(457)
$C_9H_{10}O_3$	5-Methoxy-*o*-toluic acid	25	0.0005–0.0002	378	5.2×10^{-5}	(457)
$C_9H_{10}O_3$	3-Methoxy-*p*-toluic acid	25	0.004–0.0002	378	4.04×10^{-5}	(457)
$C_9H_{10}O_3$	α-Phenoxypropionic acid	25	(?)	(?)	7.75×10^{-4}	(56)
$C_9H_{10}O_3$	β-Phenoxypropionic acid	25	(?)	(?)	5.4×10^{-5}	(56)
$C_9H_{10}O_3$	β-Phenyl-α-hydroxypropionic acid	25	0.12–0.001	378	1.85×10^{-4}	(10, 79, 195)
$C_9H_{10}O_3$	β-Phenyl-β-hydroxypropionic acid	25	0.12–0.001	378	3.90×10^{-5}	(10, 79, 195)
$C_9H_{10}O_3$	*l*-Phenylmethoxyacetic acid	25	0.03–0.001	378	7.4×10^{-4}	(195, 389)
$C_9H_{10}O_3$	Phloretic acid	25	0.016–0.001	378	2.01×10^{-5}	(436)
$C_9H_{10}O_3$	Tropic acid	25	0.03–0.001	378	7.7×10^{-5}	(378); *cf.* (436)
$C_9H_{10}O_3$	*p*-Xylenecarboxylic acid	25	0.0016–0.0008	378	6.0×10^{-4}	(378)
$C_9H_{10}O_4$	Dehydrodiacetyllevulinic acid	25	0.004–0.0005	377	6.7×10^{-5}	(381)
$C_9H_{10}O_4$	β-Phenylglyceric acid (M. P., 141°)	25	0.5–0.004	376	2.35×10^{-4}	(75)
$C_9H_{10}O_4$	β-Phenylglyceric acid (M. P., 121°)	25	0.5–0.004	376	2.54×10^{-4}	(75)
$C_9H_{10}O_4$	Veratric acid	25	0.004–0.001	378	3.54×10^{-5}	(436)
$C_9H_{10}O_5$	Ethyl gallate	25	0.03–0.004	376	9×10^{-8}	(135)
$C_9H_{11}NO$	Hydroxyhydrindamine	25	0.03–0.004	220	1.35×10^{-6}	(459)
$C_9H_{11}NO_2$	α-Anilinopropionic acid	25	0.008–0.001	376	2.05×10^{-5}	(579)
$C_9H_{11}NO_2$	β-Anilinopropionic acid	25	0.005–0.0012	376	3.8×10^{-6}	(579)
$C_9H_{11}NO_2$	*o*-Dimethylaminobenzoic acid	25	0.125	378	$\Lambda_{0.125} = 0.065$	(140)
$C_9H_{11}NO_2$	*m*-Dimethylaminobenzoic acid	25	0.008–0.001	378	6×10^{-6}	(140)
$C_9H_{11}NO_2$	*p*-Dimethylaminobenzoic acid	25	0.0004	377	8.5×10^{-6}	(297)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_9H_{11}NO_2$	*dl*-Phenyl-α-aminopropionic acid	25	0.008–0.001	375	$\Lambda_{0.008} = 3.9$	(303); *cf.* (44)
$C_9H_{11}NO_2$	*o*-Tolylaminoacetic acid	25	0.005–0.0006	377	5.8×10^{-5}	(579)
$C_9H_{11}NO_2$	*p*-Tolylaminoacetic acid	25	0.005–0.0012	377	1.5×10^{-5}	(579)
$C_9H_{11}NO_3$	*p*-Hydroxyphenyl-α-amino-propionic acid	25	0.002–0.001	(?)	$\Lambda_{0.002} = 0.5$	(304)
$C_9H_{11}NO_4S$	*o*-Toluenesulfoneaminoacetic acid	25	0.015–0.001	374	2.77×10^{-4}	(358)
$C_9H_{11}NO_4S$	*p*-Toluenesulfoneaminoacetic acid	25	0.012–0.0015	374	3.40×10^{-4}	(358)
$C_9H_{12}AsNO_5$	Methoxyacetarsanilic acid	25	0.016–0.001	370	3.0×10^{-4}	(355)
$C_9H_{12}N_2O$	*O*-Ethyl-*N*-phenylpseudourea	25	0.04–0.0012	224	5.0×10^{-7}	(107)
$C_9H_{12}N_2O$	Pseudocumenediazonium hydroxide	0	0.008–0.002	137	$\Lambda_{0.008} = 107$	(166)
$C_9H_{12}O_3$	Phenoxymethylglycol	25	0.12–0.016	(?)	$\Lambda_{0.125} = 0.04$	(65)
$C_9H_{12}O_3S$	2-Pseudocumene-5-sulfonic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 340$	(434)
$C_9H_{12}O_4$	Diallylmalonic acid	25	0.03–0.004	378	7.3×10^{-3}	(577)
$C_9H_{13}N$	Dimethylbenzylamine	25	0.05–0.0017	227	8.5×10^{-6}	(207)
$C_9H_{13}NO_3$	Isobutyl cyanoacetoacetate	25	0.002–0.001	378	6.5×10^{-4}	(214)
$C_9H_{13}NO_3$	Methyl cyanoisovalerylacetate	25	(?)	376	7×10^{-4}	(215)
$C_9H_{14}O_2$	*cis-trans-dl*-Campholytic acid	25	0.01–0.0013	377	9.1×10^{-6}	(584)
$C_9H_{14}O_2$	Isocampholytic acid	25	0.0012–0.0006	377	8.5×10^{-6}	(585)
					8.0×10^{-6}	(424)
$C_9H_{14}O_2$	*l*-Campholytic acid	25	0.006–0.0016	377	9.8×10^{-6}	(424)
$C_9H_{14}O_2$	Lauronolic acid	(?)	(?)	(?)	1.36×10^{-5}	(423)
$C_9H_{14}O_2$	Δ^1-Tetrahydro-2, 6-dimethylbenzoic acid	25	0.0013–0.0010	378	4.25×10^{-5}	(290)
$C_9H_{14}O_2$	Δ^3-Tetrahydro-2, 6-dimethylbenzoic acid	25	0.0013–0.0010	378	4.08×10^{-5}	(290)
$C_9H_{14}O_3$	Isooctic acid	25	0.004–0.002	376	7.5×10^{-5}	(569)
$C_9H_{14}O_4$	Allylpropylmalonic acid	25	0.03–0.002	378	9.0×10^{-3}	(270)
$C_9H_{14}O_4$	Allylisopropylmalonic acid	25	0.03–0.002	378	1.4×10^{-2}	(270)
$C_9H_{14}O_4$	*meso-sym.*-Ethylallylsuccinic acid	25	0.06–0.002	376	3.5×10^{-4}	(577)
$C_9H_{14}O_4$	*p-sym.*-Ethylallylsuccinic acid	25	0.03–0.001	376	2.6×10^{-4}	(577)
$C_9H_{14}O_4$	Cyclopentane-1, 1-diacetic acid	25	0.008–0.0005	(?)	1.73×10^{-4}	(525.2)
$C_9H_{14}O_4$	*sym.*-Tetramethyl-β-hydroxyglutaric acid lactone (*a* acid)	25	0.03–0.002	377	1.5×10^{-3}	(403)
$C_9H_{14}O_4$	*sym.*-Tetramethyl-β-hydroxyglutaric acid lactone (*b* acid)	25	0.01–0.001	377	1.3×10^{-3}	(403)
$C_9H_{14}O_6$	*l*-Camphoronic acid	25	0.03–0.0005	378	1.72×10^{-4}	(436)
$C_9H_{14}O_6$	α, α'-Dimethyl-β-acetoxyglutaric acid	25	0.03–0.001	374	1.97×10^{-4}	(471, 550)
$C_9H_{14}O_6$	α, δ-Dimethylbutane-α,β,δ-tricarboxylic acid	25	0.012–0.0015	376	1.58×10^{-4}	(263)
$C_9H_{14}O_6$	α(?)-Monomethyl α, α-dimethyltricarballylate	25	0.08–0.004	375	1.8×10^{-4}	(98)
$C_9H_{14}O_6$	β(?)-Monomethyl α, α-dimethyltricarballylate	25	0.11–0.014	375	8.6×10^{-5}	(98)
$C_9H_{14}O_6$	Methylethylcarboxyglutaric acid	25	0.03–0.004	375	9.5×10^{-3}	(578)
$C_9H_{14}O_6$	Propyltricarballylic acid	25	0.03–0.001	375	3.0×10^{-4}	(578)
$C_9H_{14}O_6$	Isopropyltricarballylic acid	25	0.03–0.001	375	4.25×10^{-4}	(578)
$C_9H_{14}O_6$	Terpylonic acid	25	0.03–0.001	378	1.02×10^{-4}	(511)
$C_9H_{14}O_6$	α, α, γ-Trimethyltricarballylic acid	25	0.03–0.001	376	1.4×10^{-4}	(154, 263)
$C_9H_{14}O_6$	?, ?, ?-Trimethyltricarballylic acid	25	0.02–0.007	376	2.50×10^{-4}	(154)
$C_9H_{14}O_7$	α-Hydroxycamphoronic acid	25	0.016–0.002	378	3.14×10^{-3}	(436)
$C_9H_{14}O_7$	β-Hydroxycamphoronic acid	25	0.016–0.002	378	6.2×10^{-3}	(436)
$C_9H_{15}NO$	Trimethylphenylammonium hydroxide	25	0.004	(?)	$\Lambda_{0.004} = 190$	(246)
$C_9H_{15}NO_2$	*o*-Trimethylaminophenol	25	0.03	(?)	$\Lambda_{0.03} = 1.8$	(236)
$C_9H_{15}NO_2$	*m*-Trimethylaminophenol	25	0.03	(?)	$\Lambda_{0.03} = 2.3$	(236)
$C_9H_{15}NO_2$	*p*-Trimethylaminophenol	25	0.03	(?)	$\Lambda_{0.03} = 2.8$	(236)
$C_9H_{16}O_2$	Cyclohexanepropionic acid	25	0.005–0.0007	378	1.32×10^{-5}	(635)
$C_9H_{16}O_2$	1, 3-Dimethylcyclohexane-3-carboxylic acid	25	0.004–0.0009	378	6.2×10^{-6}	(635)
$C_9H_{16}O_2$	*cis*-1, 3-Dimethylcyclohexane-5-carboxylic acid	25	0.004–0.001	378	1.05×10^{-5}	(635)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_9H_{16}O_2$	*trans*-1, 3-Dimethylcyclohexane-5-carboxylic acid	25	0.003–0.0008	378	1.07×10^{-5}	(635)
$C_9H_{16}O_2$	Hexahydro-2, 6-dimethylbenzoic acid	25	0.0013–0.0010	378	1.28×10^{-5}	(290)
$C_9H_{16}O_2$	1-Methylcyclohexane-3-acetic acid.	25	0.005–0.0006	378	1.56×10^{-5}	(635)
$C_9H_{16}O_3$	*c i s*-Hydroxydihydrocampholytic acid	25	0.012–0.003	377	3.6×10^{-5}	(424)
$C_9H_{16}O_3$	*trans*-Hydroxydihydrocampholytic acid	25	0.013–0.003	377	8.1×10^{-6}	(424)
$C_9H_{16}O_4$	Azelaic acid	25	0.012–0.0007	376	2.88×10^{-5}	(49, 565); *cf.* (524)
$C_9H_{16}O_4$	α-*sym.*-Diethylglutaric acid	25	0.007–0.0005	377	5.4×10^{-5}	(20, 49, 451)
$C_9H_{16}O_4$	β-*sym.*-Diethylglutaric acid	25	0.01–0.0007	377	5.9×10^{-5}	(20, 451)
$C_9H_{16}O_4$	β, β-Diethylglutaric acid	25	0.03–0.001	(?)	3.4×10^{-4}	(525.2)
$C_9H_{16}O_4$	Monoethyl diethylmalonate	25	0.03–0.0009	375	2.30×10^{-4}	(582)
$C_9H_{16}O_4$	*anti*-α, α'-Dimethylpimelic acid	25	(?)	(?)	3.43×10^{-5}	(317)
$C_9H_{16}O_4$	*para*-α, α'-Dimethylpimelic acid	25	(?)	(?)	3.44×10^{-5}	(317)
$C_9H_{16}O_4$	α, α-Dimethyl-α'-isopropylsuccinic acid	25	0.015–0.002	375	1.57×10^{-4}	(97)
$C_9H_{16}O_4$	Dimethylpropylsuccinic acid	25	0.016–0.001	376	5.4×10^{-4}	(577)
					5.9×10^{-4}	(97)
$C_9H_{16}O_4$	Dipropylmalonic acid	25	0.016–0.001	376	1.06×10^{-2}	(390, 524, 535)
		0–65	0.03–0.0005			(526)
$C_9H_{16}O_4$	Ethylbutylmalonic acid	25	0.03–0.001	375	9.1×10^{-3}	(390)
$C_9H_{16}O_4$	Ethylisobutylmalonic acid	25	0.03–0.001	375	1.5×10^{-2}	(390)
$C_9H_{16}O_4$	Methylisoamylmalonic acid	25	0.03–0.001	375	1.84×10^{-3}	(390)
$C_9H_{16}O_4$	*cis*-α, α'-Methylisobutylsuccinic acid	25	0.03–0.004	375	4.27×10^{-4}	(97)
$C_9H_{16}O_4$	*trans*-α, α'-Methylisobutylsuccinic acid	25	0.01–0.0014	375	2.35×10^{-4}	(97)
$C_9H_{16}O_4$	α-*sym.*-Methylpropylglutaric acid.	25	0.016–0.002	376	5.3×10^{-5}	(60)
$C_9H_{16}O_4$	β-*sym.*-Methylpropylglutaric acid.	25	0.03–0.002	376	5.8×10^{-5}	(60)
$C_9H_{16}O_4$	α-Propyladipic acid	24.4	0.03–0.0016	375	4.0×10^{-5}	(391)
$C_9H_{16}O_4$	Monomethyl tetramethylsuccinate	25	0.02–0.003	374	1.22×10^{-5}	(100)
$C_9H_{16}O_5$	*sym.*-Tetramethyl-β-hydroxyglutaric acid	25	0.04–0.0006	376	1.32×10^{-4}	(402)
$C_9H_{18}O_2$	Pelargonic acid	25	0.0008–0.0004	377	1.1×10^{-5}	(200)
$C_9H_{18}O_3$	Dimethyl-β-isobutylethylenelactic acid	25	0.03–0.002	375	1.45×10^{-5}	(550)
$C_9H_{21}N$	Tripropylamine	25	0.005–0.002	224	4.5×10^{-4}	(104)
$C_{10}H_5NO_{10}$	Pyridinepentacarboxylic acid	25	0.004–0.0002	(?)	$\Lambda_{0.004} = 650$	(436)
$C_{10}H_6N_2O_8S$	2, 4-Dinitro-1-naphthol-7-sulfonic acid	18	0.01–0.0006	(?)	$[\Lambda_{0.91} = 416]$	(324)
		25	0.01–0.0012	(?)	$\Lambda_{0.01} = 245$	(445)
		90	0.01–0.0012	(?)	$[\Lambda_{0.01} = 754]$	(324)
$C_{10}H_6O_8$	Pyromellitic acid	25	0.014–0.0009	(?)	$\Lambda_{0.014} = 260$	(49)
$C_{10}H_7NO_2$	Cinchoninic acid	25	0.016–0.001	380	1.25×10^{-5}	(436)
$C_{10}H_7NO_2$	1-Nitroso-2-naphthol	25	0.002–0.001	376	2.5×10^{-8}	(557)
$C_{10}H_7NO_2$	2-Nitroso-1-naphthol	25	0.002–0.001	376	2.5×10^{-8}	(557)
$C_{10}H_7NO_2$	4-Nitroso-1-naphthol	25	0.001–0.0005	376	2.6×10^{-7}	(557)
$C_{10}H_7NO_2$	Quinaldinic acid	25	0.008–0.001	380	1.2×10^{-5}	(436)
$C_{10}H_7NO_3$	Phenylisoxazolecarboxylic acid	25	0.005–0.0007	377	5.4×10^{-3}	(7)
$C_{10}H_7NO_4$	*o*-Phthalylaminoacetic acid	25	0.016–0.001	377	9.8×10^{-4}	(436)
$C_{10}H_7NO_5S$	1, 5-Nitronaphthalenesulfonic acid.	25	(?)	(?)	$[1.5 \times 10^{-1}]$	(194)
$C_{10}H_7NO_5S$	1, 6-Nitronaphthalenesulfonic acid.	25	(?)	(?)	$[1.0 \times 10^{-1}]$	(194)
$C_{10}H_7NO_5S$	1, 7-Nitronaphthalenesulfonic acid.	25	(?)	(?)	$[1.3 \times 10^{-1}]$	(194)
$C_{10}H_7NO_5S$	1, 8-Nitronaphthalenesulfonic acid.	25	(?)	(?)	$[9.4 \times 10^{-2}]$	(194)
$C_{10}H_7NO_{11}S_3$	1, 3, 6, 8-Nitronaphthalenetrisulfonic acid	25	(?)	(?)	$[5.5 \times 10^{-2}]$	(194)
$C_{10}H_8Cl_2O_4$	Monoethyl 3, 6-dichlorophthalate	25	0.004–0.001	376	1.5×10^{-2}	(598)
$C_{10}H_8O$	α-Naphthol	25	0.002–0.001	379	$[1 \times 10^{-8}]$	(569)
$C_{10}H_8O_2$	1, 2-Dihydroxynaphthalene	25	0.16–0.002	(?)	$\Lambda_{0.16} = 0.026$	(66, 70)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{10}H_8O_2$	2, 3-Dihydroxynaphthalene	25	0.005–0.001	(?)	$\Lambda_{0.005} = 0.12$	(70)
$C_{10}H_8O_3S$	α-Naphthalenesulfonic acid	25	0.03–0.001	(?)	$\Lambda_{0.03} = 339$	(434)
$C_{10}H_8O_3S$	β-Naphthalenesulfonic acid	25	0.42–0.0005	378	$\Lambda_{0.04} = 354$	(312, 466, 603)
$C_{10}H_8O_4$	Benzalmalonic acid	25	0.03–0.001	378	4.04×10^{-3}	(436)
$C_{10}H_8O_4$	Benzoylpyroracemic acid	25	0.0025–0.0003	379	6×10^{-3}	(7)
$C_{10}H_8O_4$	*allo*-Piperonylacrylic acid	25	0.0025–0.0006	377	1.04×10^{-4}	(488)
$C_{10}H_8O_4$	Piperonylacrylic acid	25	0.00013	377	2.4×10^{-5}	(488)
$C_{10}H_8O_5$	Monomethyl phthalonate	25	0.01–0.001	378	1.5×10^{-4}	(540)
$C_{10}H_8O_6$	1-Monomethyl trimellitate	25	0.016–0.001	377	1.8×10^{-3}	(601)
$C_{10}H_8O_6$	2-Monomethyl trimellitate	25	0.016–0.001	377	2.6×10^{-3}	(601)
$C_{10}H_8O_6$	4-Monomethyl trimellitate	25	0.016–0.001	377	2.86×10^{-3}	(601)
$C_{10}H_9BrO_5$	Bromoopianic acid	25	0.002–0.001	377	4.30×10^{-5}	(601)
$C_{10}H_9NO_2$	3-Methylindole-3-carboxylic acid	25	0.002–0.0005	376	4.6×10^{-5}	(7)
$C_{10}H_9NO_2$	*Pr*-2-Methylindole-2-carboxylic acid	25	0.001–0.0002	376	1.2×10^{-6}	(7)
$C_{10}H_9NO_3S$	1-Naphthylamine-2-sulfonic acid	25	0.016–0.0005	376	2×10^{-2}	(165)
$C_{10}H_9NO_3S$	1-Naphthylamine-4-sulfonic acid	25	0.001–0.0001	376	$\Lambda_{0.001} = 276$	(165)
		0–65	0.001–0.0005			(526)
$C_{10}H_9NO_3S$	1-Naphthylamine-5-sulfonic acid	25	0.004–0.0005	377	2.3×10^{-4}	(165)
$C_{10}H_9NO_3S$	1-Naphthylamine-6-sulfonic acid	25	0.004–0.0001	377	1.92×10^{-4}	(165)
$C_{10}H_9NO_3S$	1-Naphthylamine-7-sulfonic acid	25	0.008–0.0005	377	2.22×10^{-4}	(165)
$C_{10}H_9NO_3S$	1-Naphthylamine-8-sulfonic acid	25	0.001–0.0001	377	1.00×10^{-5}	(165)
$C_{10}H_9NO_3S$	2-Naphthylamine-5-sulfonic acid	25	0.004–0.0002	377	9.2×10^{-5}	(165)
$C_{10}H_9NO_3S$	2-Naphthylamine-6(?)-sulfonicacid	25	0.001–0.0001	377	1.63×10^{-4}	(165)
$C_{10}H_9NO_3S$	2-Naphthylamine-7-sulfonic acid	25	0.002–0.0002	377	1.0×10^{-4}	(165)
$C_{10}H_9NO_3S$	2-Naphthylamine-8-sulfonic acid	25	0.002–0.0002	377	1.20×10^{-4}	(165)
$C_{10}H_9NO_5$	2-Acetylaminoterephthalic acid	25	0.0016–0.0005	377	$\Lambda_{0.001} = 242.0$	(540, 601)
$C_{10}H_9NO_5$	4-Acetylaminoisophthalic acid	25	0.0004	377	7.9×10^{-4}	(600)
					1.1×10^{-3}	(599)
$C_{10}H_9NO_6$	2, 4-Dimethylpyridinetricarboxylic acid	25	0.03–0.0002	(?)	$\Lambda_{0.03} = 319$	(320)
$C_{10}H_9NO_6$	1-Monoethyl 4-nitrophthalate	25	0.01–0.0007	377	3.02×10^{-3}	(601)
$C_{10}H_9NO_6$	2-Monomethyl 4-nitrophthalate	25	0.01–0.0006	377	5.1×10^{-3}	(601)
$C_{10}H_9NO_6S_2$	1-Naphthylamine-2, 5(?)-disulfonic acid	25	0.016–0.0002	374	$\Lambda_{0.016} = 338$	(165)
$C_{10}H_9NO_6S_2$	1-Naphthylamine-4, 6-disulfonic acid	25	0.016–0.0001	374	$\Lambda_{0.016} = 210$	(165)
$C_{10}H_9NO_6S_2$	1-Naphthylamine-4, 7-disulfonic acid	25	0.03–0.0002	374	$\Lambda_{0.03} = 186$	(165)
$C_{10}H_9NO_6S_2$	2-Naphthylamine-4, 8-disulfonic acid	25	0.016–0.0005	374	$\Lambda_{0.016} = 120$	(165)
$C_{10}H_9NO_7$	Nitroopianic acid	25	0.004–0.001	377	2.85×10^{-6}	(540)
$C_{10}H_9NO_8$	Nitrohemipinic acid	25	0.03–0.002	376	2.1×10^{-2}	(540, 604)
$C_{10}H_9NO_9S_3$	1-Naphthylamine-2, 4, 7-trisulfonic acid	25	0.02–0.0006	374	$\Lambda_{0.02} = 181$	(165)
$C_{10}H_9NO_9S_3$	1-Naphthylamine-3, 6, 8-trisulfonic acid	25	0.01–0.0002	374	$\Lambda_{0.01} = 198$	(165)
$C_{10}H_9N_3O_2$	3-Methyl-1-phenyl-4-isonitroso-5-pyrazolone	25	0.004–0.001	376	2.3×10^{-6}	(235)
$C_{10}H_9N_3O_3$	Methyl 1-phenyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate	25	0.007–0.0009	375	$[1.6 \times 10^{-2}]$	(157)
		50	0.01–0.0013	499	$[1.3 \times 10^{-2}]$	(157)
$C_{10}H_{10}BrNO_3$	Acetylbromophenylaminoacetic acid	25	0.003–0.0008	378	2.80×10^{-4}	(579)
$C_{10}H_{10}BrNO_3$	Bromoacetylphenylaminoacetic acid	25	0.005–0.0006	378	3.3×10^{-4}	(579)
$C_{10}H_{10}ClNO_3$	Chloroacetylphenylaminoacetic acid	25	0.005–0.0006	379	3.33×10^{-4}	(579)
$C_{10}H_{10}ClNO_3$	*o*-Chlorosuccinanilic acid	25	0.008–0.001	376	2.04×10^{-5}	(436)
$C_{10}H_{10}ClNO_3$	*m*-Chlorosuccinanilic acid	25	0.008–0.001	376	2.05×10^{-5}	(436)
$C_{10}H_{10}ClNO_3$	*p*-Chlorosuccinanilic acid	25	0.008–0.001	376	2.05×10^{-5}	(436)
$C_{10}H_{10}O_3$	β-Benzoylpropionic acid	25	0.016–0.001	377	2.23×10^{-5}	(244)
$C_{10}H_{10}O_3$	Furyldihydroresorcinol	25	0.003–0.0004	377	1.48×10^{-5}	(508)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{10}H_{10}O_3$	*allo*-*p*-Methoxycinnamic acid	25	0.01–0.0012	377	8.85×10^{-5}	(488)
$C_{10}H_{10}O_3$	*p*-Methoxycinnamic acid	25	0.0004–0.0002	377	2.0×10^{-5}	(488)
$C_{10}H_{10}O_3$	Methylcoumaric acid	25	0.0005–0.0004	377	1.98×10^{-5}	(488)
$C_{10}H_{10}O_3$	Methylcoumarinic acid	25	0.004–0.001	377	5.15×10^{-5}	(488)
$C_{10}H_{10}O_4$	Benzylmalonic acid	25	0.03–0.001	378	1.52×10^{-3}	(577)
		0–65	0.03–0.0005			(526)
$C_{10}H_{10}O_4$	1-Monomethyl homophthalate	25	0.002–0.001	378	4.29×10^{-5}	(540)
$C_{10}H_{10}O_4$	2-Monomethyl homophthalate	25	0.004–0.001	378	7.5×10^{-5}	(540)
$C_{10}H_{10}O_4$	1-Monomethyl2-methylterephthalate	25	0.002–0.001	377	1.56×10^{-4}	(601)
$C_{10}H_{10}O_4$	4-Monomethyl 2-methylterephthalate	25	0.002–0.0005	377	5.5×10^{-4}	(601)
$C_{10}H_{10}O_4$	*o*-Phenylenediacetic acid	25	0.015–0.0009	376	1.08×10^{-4}	(34)
$C_{10}H_{10}O_4$	Phenylsuccinic acid	25	0.016–0.0005	376	1.58×10^{-4}	(450, 602)
$C_{10}H_{10}O_4$	Monoethyl phthalate	25	0.008–0.0005	376	5.50×10^{-4}	(582)
$C_{10}H_{10}O_5$	Benzyltartronic acid	25	0.014–0.0009	378	5.3×10^{-3}	(577)
$C_{10}H_{10}O_5$	1-Monoethyl 4-hydroxyphthalate	25	0.004–0.001	377	7.2×10^{-4}	(601)
$C_{10}H_{10}O_5$	2-Monoethyl 4-hydroxyphthalate	25	0.004–0.001	377	2.15×10^{-4}	(601)
$C_{10}H_{10}O_5$	Dimethyl 4-hydroxyphthalate	25	0.008–0.001	376	1×10^{-7}	(598)
$C_{10}H_{10}O_5$	Opianic acid	25	0.008–0.001	378	8.64×10^{-4}	(436)
$C_{10}H_{10}O_6$	Apiolic acid	25	0.0008	377	8.0×10^{-5}	(7)
$C_{10}H_{10}O_6$	Hemipinic acid	25	0.06–0.001	376	1.10×10^{-3}	(318, 598)
$C_{10}H_{10}O_6$	*m*-Hemipinic acid	25	0.016–0.0005	378	1.42×10^{-3}	(436)
$C_{10}H_{11}NO$	Methylquinolinium hydroxide	25	0.03	(?)	$\Lambda_{0.03} = 208$	(241)
$C_{10}H_{11}NO$	Methylisoquinolinium hydroxide	25	0.03	(?)	$\Lambda_{0.03} = 207$	(241)
$C_{10}H_{11}NO_3$	Benzoylaminopropionic acid	25	0.008–0.001	376	1.92×10^{-4}	(200)
$C_{10}H_{11}NO_3$	β-Benzoylpropionic acid oxime (stable)	25	0.016–0.004	378	1.7×10^{-5}	(244)
$C_{10}H_{11}NO_3$	Methylbenzoylaminoacetic acid	25	0.016–0.001	376	4.95×10^{-4}	(200)
$C_{10}H_{11}NO_3$	Phenaceturic acid	25	0.007–0.001	376	1.98×10^{-4}	(200)
$C_{10}H_{11}NO_3$	Phenylacetylaminoacetic acid	25	0.005–0.0006	378	2.58×10^{-4}	(579)
$C_{10}H_{11}NO_3$	Succinanilic acid	25	0.016–0.001	376	1.99×10^{-5}	(436)
$C_{10}H_{11}NO_3$	*o*-Toluric acid	25	0.004–0.001	376	1.89×10^{-4}	(200)
$C_{10}H_{11}NO_3$	*m*-Toluric acid	25	0.004–0.0005	376	2.06×10^{-4}	(200)
$C_{10}H_{11}NO_3$	*p*-Toluric acid	25	0.004–0.0005	376	1.96×10^{-4}	(200)
$C_{10}H_{11}NO_4$	1-Monoethyl 4-aminoisophthalate	25	0.001–0.0003	376	4.0×10^{-5}	(601)
$C_{10}H_{11}NO_4$	Anisuric acid	25	0.0014–0.0004	376	1.59×10^{-4}	(200)
$C_{10}H_{11}NO_4$	4-Dimethylaminoisophthalic acid	25	0.001–0.0005	376	2.63×10^{-4}	(601)
$C_{10}H_{11}NO_4$	Dimethylaminoterephthalic acid	25	0.002–0.0005	376	4.5×10^{-4}	(601)
$C_{10}H_{11}NO_4$	4-Monomethyl 2-methylaminoterephthalate	25	0.001–0.0005	376	3.6×10^{-5}	(601)
$C_{10}H_{11}NO_4$	3-Nitrocumic acid	25	0.0005–0.0002	375	2.1×10^{-4}	(49)
$C_{10}H_{11}NO_4$	*eso*-Monomethyl phenylglycine-*o*-carboxylate	25	0.0012–0.0003	376	1.3×10^{-4}	(394)
$C_{10}H_{11}NO_4$	*exo*-Monomethyl phenylglycine-*o*-carboxylate	25	0.003–0.0004	376	2.7×10^{-5}	(394)
$C_{10}H_{11}NO_4$	Phenyliminodiacetic acid	25	0.005–0.0012	375	2.65×10^{-3}	(579)
$C_{10}H_{11}NO_5$	1-Hemipinamic acid	25	0.016–0.001	376	3.9×10^{-4}	(393)
$C_{10}H_{11}NO_5$	2-Hemipinamic acid	25	0.016–0.001	376	6.8×10^{-5}	(393)
$C_{10}H_{11}NO_6S$	Benzenesulfoneaminosuccinic acid	25	0.04–0.0006	374	7.01×10^{-4}	(358)
$C_{10}H_{11}N_3OS$	1-Phenyl-3-ethylthiourazole	25	0.0005–0.0002	378	5×10^{-7}	(6)
$C_{10}H_{11}N_3O_2$	1-Phenyl-3-ethoxyurazole	25	0.001–0.0001	376	4×10^{-8}	(6)
$C_{10}H_{12}O_2$	Cumic acid	25	0.002–0.001	376	4.9×10^{-5}	(436)
$C_{10}H_{12}O_2$	2, 3, 4-Trimethylbenzoic acid	25	0.002–0.0005	376	3.3×10^{-5}	(105, 451)
$C_{10}H_{12}O_2$	2, 4, 5-Trimethylbenzoic acid	25	0.001–0.0005	376	9.5×10^{-5}	(451)
$C_{10}H_{12}O_2$	2, 4, 6-Trimethylbenzoic acid	25	0.008–0.001	377	3.7×10^{-4}	(105, 451)
$C_{10}H_{12}O_3$	5-Isopropylsalicylic acid	25	0.0012–0.0006	376	7.2×10^{-4}	(378)
$C_{10}H_{12}O_3$	3-Ethoxy-*p*-toluic acid	25	0.002–0.0005	376	3.4×10^{-5}	(457)
$C_{10}H_{12}O_3$	α-Methyl-β-phenyl-β-hydroxypropionic acid	25	0.03–0.0008	375	3.42×10^{-5}	(550)
$C_{10}H_{12}O_3$	Phenylethoxyacetic acid	25	0.05–0.0014	377	5.2×10^{-4}	(195)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{10}H_{12}O_3$	α-Phenoxybutyric acid	25	(?)	(?)	6.82×10^{-4}	(57)
$C_{10}H_{12}O_3$	α-Phenoxyisobutyric acid	25	(?)	(?)	4.34×10^{-4}	(57)
$C_{10}H_{12}O_8$	1, 1, 3, 3-Hexamethylenetetracarboxylic acid	25	0.05–0.0015	373	1.3×10^{-3}	(582)
$C_{10}H_{13}NO_2$	α-Anilinobutyric acid	25	0.008–0.001	373	2.8×10^{-5}	(579)
$C_{10}H_{13}NO_2$	α-Anilinoisobutyric acid	25	0.005–0.0012	373	3.6×10^{-5}	(579)
$C_{10}H_{13}NO_2$	β-Anilinoisobutyric acid	25	0.005–0.0012	373	1.0×10^{-6}	(579)
$C_{10}H_{13}NO_2$	α-*o*-Toluidinopropionic acid	25	0.005–0.0012	373	3.8×10^{-5}	(579)
$C_{10}H_{13}NO_2$	α-*p*-Toluidinopropionic acid	25	0.002–0.001	373	6.7×10^{-6}	(579)
$C_{10}H_{13}NO_2$	β-*p*-Toluidinopropionic acid	25	0.005–0.0012	373	2.2×10^{-6}	(579)
$C_{10}H_{13}NO_4S$	*m*-Xylenesulfoneaminoacetic acid	25	0.014–0.002	373	2.65×10^{-4}	(358)
$C_{10}H_{13}N_4O_8P$	Inosinic acid	25	0.07–0.0005	375	$\Lambda_{0.07} = 122$	(220)
$C_{10}H_{14}N_2$	Nicotine	25	0.03–0.001	(?)	$\Lambda_{0.03} = 2.0$	(416)
$C_{10}H_{14}O$	Isobutylphenol	25	0.003–0.0008	379	2.6×10^{-7}	(26)
$C_{10}H_{14}O_4$	Diisopropylenesuccinic acid	25	0.008–0.001	375	1.4×10^{-4}	(152)
$C_{10}H_{14}O_4$	Methyl dimethylhydroresorcylate	25	0.07–0.0006	375	4.76×10^{-5}	(508)
$C_{10}H_{14}O_4$	Ethyl methylhydroresorcylate	25	0.06–0.0008	375	3.63×10^{-5}	(508)
$C_{10}H_{15}BrO_4S$	*o*-Bromocamphorsulfonic acid	25	0.5–0.001	378	$\Lambda_{0.033} = 351$	(580)
$C_{10}H_{15}NO_3$	Isoamyl cyanoacetoacetate	25	0.001–0.0005	376	5.5×10^{-4}	(214)
$C_{10}H_{16}Fe_2O_{11}$	Diferripentaacetyl hydroxide	25	0.03–0.001	(?)	$\Lambda_{0.03} = 9.3$	(478)
$C_{10}H_{16}O_2$	Campholenic acid	18	0.003–0.0003	340	1.65×10^{-5}	(594)
$C_{10}H_{16}O_2$	Fencholenic acid	18	0.003–0.0003	340	1×10^{-5}	(594)
$C_{10}H_{16}O_3$	Pinonic acid	25	0.005–0.001	375	2.1×10^{-5}	(487)
$C_{10}H_{16}O_3$	α-Tanacetoneketocarboxylic acid	25	0.01–0.0025	375	1.1×10^{-5}	(487)
$C_{10}H_{16}O_4$	*d*-Camphoric acid	25	0.016–0.0005	378	2.20×10^{-5}	(436, 534, 570, 620)
		0–35	0.016–0.0005			(45, 48, 610, 620)
$C_{10}H_{16}O_4$	*l*-Camphoric acid	25	(?)	378	2.20×10^{-5}	(570)
$C_{10}H_{16}O_4$	*dl*-Camphoric acid	25	(?)	378	2.20×10^{-5}	(570)
$C_{10}H_{16}O_4$	*d*-Isocamphoric acid	25	(?)	378	1.70×10^{-5}	(570)
$C_{10}H_{16}O_4$	*l*-Isocamphoric acid	25	0.014–0.0018	378	1.58×10^{-5}	(593)
					1.70×10^{-5}	(570)
$C_{10}H_{16}O_4$	*dl*-Isocamphoric acid	25	(?)	378	1.70×10^{-4}	(570)
$C_{10}H_{16}O_4$	Cyclohexane-1, 1-diacetic acid	25	0.004–0.001	(?)	3.37×10^{-4}	(525.5)
$C_{10}H_{16}O_4$	*cis-d*-Isofenchocamphoric acid	25	0.016–0.002	377	4.84×10^{-5}	(499)
$C_{10}H_{16}O_4$	*cis-l*-Isofenchocamphoric acid	25	0.016–0.002	377	4.84×10^{-5}	(499)
$C_{10}H_{16}O_4$	*cis-dl*-Isofenchocamphoric acid	25	0.008–0.002	377	4.82×10^{-5}	(499)
$C_{10}H_{16}O_4$	*trans-d*-Isofenchocamphoric acid	25	0.016–0.002	377	4.12×10^{-5}	(499)
$C_{10}H_{16}O_4$	*trans-l*-Isofenchocamphoric acid	25	0.016–0.002	377	4.13×10^{-5}	(499)
$C_{10}H_{16}O_4$	*trans-dl*-Isofenchocamphoric acid	25	0.008–0.002	377	4.12×10^{-5}	(499)
$C_{10}H_{16}O_4$	α, α, α′, α′-Tetramethyldihydromuconic acid	25	0.04–0.005	375	1.78×10^{-5}	(92)
$C_{10}H_{16}O_5$	Cineolic acid	25	0.06–0.001	375	1.15×10^{-4}	(378)
$C_{10}H_{16}O_6$	Propylmethylcarboxyglutaric acid	25	0.03–0.004	375	9.9×10^{-3}	(578)
$C_{10}H_{16}O_6$	α, α, γ, γ-Tetramethyltricarballylic acid	25	0.03–0.001	375	9.6×10^{-5}	(578)
					1.50×10^{-4}	(263)
$C_{10}H_{16}O_6$	*p*-Tetramethyltricarballylic acid	25	0.016–0.001	375	1.09×10^{-4}	(578)
$C_{10}H_{17}NO_3$	α-Camphoramic acid	25	0.016–0.002	376	1.4×10^{-5}	(393)
$C_{10}H_{17}NO_3$	β-Camphoramic acid	25	0.016–0.002	376	1.25×10^{-5}	(393)
$C_{10}H_{17}N_3O_5$	Antipeptone (α)	[25]	0.12–0.001	(?)	$\Lambda_{0.06} = 18.0$	(420)
$C_{10}H_{18}O_2$	Campholic acid	25	0.001–0.0005	378	4.3×10^{-6}	(436)
$C_{10}H_{18}O_3$	Oxymenthylic acid	25	0.02–0.0007	377	2.06×10^{-5}	(436)
$C_{10}H_{18}O_4$	Dihydrocamphoric acid	[25]	(?)	(?)	4.15×10^{-5}	(137)
$C_{10}H_{18}O_4$	α-Dihydroxydihydrocampholenic acid	18	0.018–0.0002	340	2.43×10^{-5}	(594)
$C_{10}H_{18}O_4$	α, α-Dimethyl-α′-isobutylsuccinic acid	25	0.004–0.0005	375	4.30×10^{-4}	(97)
$C_{10}H_{18}O_4$	*cis-sym.*-Diisopropylsuccinic acid	25	0.008–0.001	375	2.3×10^{-3}	(96); *cf.* (20)
$C_{10}H_{18}O_4$	*trans-sym.*-Diisopropylsuccinic acid	25	0.004–0.0005	375	1.08×10^{-4}	(96)
$C_{10}H_{18}O_4$	*cis-sym.*-Dipropylsuccinic acid	25	0.008–0.001	375	4.9×10^{-4}	(96)
$C_{10}H_{18}O_4$	*trans-sym.*-Dipropylsuccinic acid	25	0.004–0.0005	375	2.4×10^{-4}	(96)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{10}H_{18}O_4$	Ethylisoamylmalonic acid	25	0.03–0.001	375	8.6×10^{-3}	(390)
$C_{10}H_{18}O_4$	Heptylmalonic acid	25	0.005–0.0006	375	9.8×10^{-4}	(524, 535)
$C_{10}H_{18}O_4$	*cis*-α-Methyl-α′-isoamylsuccinic acid	25	0.02–0.0025	375	3.85×10^{-4}	(97)
$C_{10}H_{18}O_4$	*trans*-α-Methyl-α′-isoamylsuccinic acid	25	0.005–0.0007	375	2.35×10^{-4}	(97)
$C_{10}H_{18}O_4$	*cis*-α-Propyl-α′-isopropylsuccinic acid	25	0.008–0.001	376	2.90×10^{-4}	(96)
$C_{10}H_{18}O_4$	*trans*-α-Propyl-α′-isopropylsuccinic acid	25	0.004–0.0005	376	1.45×10^{-4}	(96)
$C_{10}H_{18}O_4$	Sebacic acid	25	0.004–0.0008	376	2.70×10^{-5}	(138, 565); *cf.* (436, 524)
		0–35	0.002–0.0005			(525)
$C_{10}H_{18}O_4$	Monoethyl suberate	25	0.014–0.0009	375	1.46×10^{-5}	(582)
$C_{10}H_{20}O_3$	α-Isopropyl-β-isobutylhydracrylic acid	25	0.02–0.002	376	1.9×10^{-5}	(461)
$C_{10}H_{20}O_6$	Tetramethylglucose	25	0.5	(?)	$\Lambda_{0.5} = 0.087$	(71)
$C_{10}H_{23}N$	Diisoamylamine	25	0.005–0.002	222	7.7×10^{-4}	(104)
$C_{11}H_8N_2O_2$	3, 2′-Dipyridyl-3′-carboxylic acid	25	0.016–0.001	376	1.8×10^{-5}	(436)
$C_{11}H_8N_2O_2S$	*N*-Cyano-α-naphthalenesulfamide	25	0.0005–0.00025	376	1.6×10^{-5}	(26)
$C_{11}H_8N_2O_2S$	*N*-Cyano-β-naphthalenesulfamide	25	0.0004–0.0002	376	6.6×10^{-5}	(26)
$C_{11}H_8O_2$	α-Naphthoic acid	25	0.0005	377	2.0×10^{-4}	(49)
$C_{11}H_8O_2$	β-Naphthoic acid	25	0.0003–0.0001	377	6.9×10^{-5}	(151); *cf.* (26, 49)
$C_{11}H_9NO_3$	Quininic acid	25	0.004–0.001	377	9.0×10^{-6}	(436)
$C_{11}H_{10}BrN_3O_3$	Ethyl 1-*p*-bromophenyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate	25	0.007–0.0017	375	1.5×10^{-2}	(158)
$C_{11}H_{10}O_2$	Δ^1-Dihydro-α-naphthoic acid	25	0.003–0.0001	376	7.9×10^{-5}	(49, 151, 302)
$C_{11}H_{10}O_2$	Δ^1-Dihydro-β-naphthoic acid	25	0.0005–0.0001	376	2.9×10^{-5}	(151)
$C_{11}H_{10}O_2$	Δ^2-Dihydro-α-naphthoic acid	25	0.012–0.0001	376	1.16×10^{-4}	(49, 151, 302)
$C_{11}H_{10}O_2$	Δ^2-Dihydro-β-naphthoic acid	25	0.0006–0.0001	376	2.9×10^{-5}	(26)
					2.5×10^{-5}	(151)
$C_{11}H_{10}O_2$	Δ^3-Dihydro-β-naphthoic acid	25	0.004–0.0001	376	5.05×10^{-5}	(26)
					5.75×10^{-5}	(151)
$C_{11}H_{10}O_3$	Phenyltetric acid	25	0.004–0.0009	376	1.90×10^{-4}	(573)
$C_{11}H_{10}O_4$	Acetylcoumaric acid	25	0.0007	376	4.7×10^{-5}	(488)
$C_{11}H_{10}O_4$	Acetylcoumarinic acid	25	0.006–0.001	376	1.07×10^{-4}	(488)
$C_{11}H_{10}O_4$	Phenylitaconic acid	25	0.008–0.001	376	1.35×10^{-4}	(540)
$C_{11}H_{10}O_5$	β-Benzoylisosuccinic acid	25	0.016–0.001	376	2.4×10^{-3}	(524)
$C_{11}H_{10}O_6$	1, 2-Dimethyl trimellitate	25	0.008–0.001	376	3.4×10^{-4}	(601)
$C_{11}H_{10}O_7$	Apionylglyoxylic acid	25	0.01–0.0014	376	3.2×10^{-2}	(7)
$C_{11}H_{11}NO_2$	2-Methylindole-3-acetic acid	25	0.004–0.0005	375	2.1×10^{-5}	(7)
$C_{11}H_{11}NO_5$	1-Monomethyl 2-acetylaminoterephthalate	25	0.001–0.0005	376	2.58×10^{-4}	(601)
$C_{11}H_{11}NO_5$	4-Monomethyl 2-acetylaminoterephthalate	25	0.0014–0.0003	376	7.1×10^{-4}	(540, 601)
$C_{11}H_{11}NO_5$	1-Monomethyl 4-acetylaminoisophthalate	25	0.001–0.0005	376	6.9×10^{-4}	(601)
$C_{11}H_{11}NO_5$	4-Acetylmethylaminoisophthalic acid	25	0.004–0.0005	376	$\Lambda_{0.004} = 137$	(601)
$C_{11}H_{11}NO_5$	*N*-Acetylmethylaminoterephthalic acid	25	0.006–0.0005	376	1.4×10^{-3}	(601); *cf.* (540)
$C_{11}H_{11}NO_5$	Acetylphenylglycine-*o*-carboxylic acid	25	0.02–0.0016	376	1.03×10^{-3}	(394)
$C_{11}H_{11}NO_5$	Benzoylaminosuccinic acid	25	0.016–0.004	376	5.22×10^{-4}	(442)
$C_{11}H_{11}NO_6$	Anilinodiacetic-*o*-carboxylic acid	25	0.014–0.0016	375	3×10^{-3}	(394)
$C_{11}H_{11}NO_8$	1-Monomethyl nitrohemipinate	25	0.004–0.0005	377	$\Lambda_{0.004} = 300$	(604)
$C_{11}H_{11}NO_8$	2-Monomethyl nitrohemipinate	25	0.004–0.001	377	$\Lambda_{0.004} = 307$	(604)
$C_{11}H_{12}N_2O_4$	Benzylidenehydrazinodiacetic acid	25	0.002–0.0002	(?)	$\Lambda_{0.002} = 200.5$	(29)
$C_{11}H_{12}O_2$	*ar.*-α-Tetrahydronaphthoic acid	25	0.009–0.0001	376	4.38×10^{-5}	(49, 151)
$C_{11}H_{12}O_2$	β-Tetrahydronaphthoic acid	25	0.005–0.0006	376	2.45×10^{-5}	(26, 151)
$C_{11}H_{12}O_3$	Ethylcoumaric acid	25	0.0005	376	2.0×10^{-5}	(488)
$C_{11}H_{12}O_3$	Ethylcoumarinic acid	25	0.003–0.0009	376	4.35×10^{-5}	(488)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{11}H_{12}O_3$	Mesityleneglyoxylic acid	25	0.03–0.001	376	$\Lambda_{0.03} = 258$	(69, 105)
$C_{11}H_{12}O_4$	Benzylsuccinic acid	25	0.016–0.002	375	8.9×10^{-5}	(577)
$C_{11}H_{12}O_4$	1-Monoethyl homophthalate	25	0.002–0.001	375	4.5×10^{-5}	(540)
$C_{11}H_{12}O_4$	2-Monoethyl homophthalate	25	0.004–0.001	375	7.0×10^{-5}	(540)
$C_{11}H_{12}O_4$	Mesitylenedicarboxylic acid	25	0.016–0.001	376	9.6×10^{-4}	(105)
$C_{11}H_{12}O_4$	Methylbenzylmalonic acid	25	0.016–0.0005	375	2.6×10^{-3}	(524)
$C_{11}H_{12}O_4$	*fum.-sym.*-Methylphenylsuccinic acid	25	0.02–0.0008	375	3.64×10^{-4}	(631)
$C_{11}H_{12}O_4$	*mal.-sym.*-Methylphenylsuccinic acid	25	0.02–0.0008	375	2.25×10^{-4}	(631)
$C_{11}H_{12}O_4$	Phenylglutaric acid	25	0.03–0.003	376	7.62×10^{-5}	(567)
$C_{11}H_{12}O_4$	α-Monomethyl phenylsuccinate	25	0.002–0.0005	375	4.8×10^{-5}	(602)
$C_{11}H_{12}O_4$	β-Monomethyl phenylsuccinate	25	0.004–0.0005	375	1.05×10^{-4}	(540, 602)
$C_{11}H_{12}O_4S_2$	Benzylidenebisthioglycolic acid	25	0.008–0.002	376	6×10^{-4}	(280)
$C_{11}H_{12}O_6$	1-Monomethyl hemipinate	25	0.008–0.001	375	1.26×10^{-3}	(436, 605)
$C_{11}H_{12}O_6$	2-Monomethyl hemipinate	25	0.008–0.001	375	1.60×10^{-4}	(436, 605)
$C_{11}H_{13}NO_3$	α-Acetylanilinopropionic acid	25	0.008–0.001	375	1.22×10^{-4}	(579)
$C_{11}H_{13}NO_3$	Acetyl-*o*-tolylaminoacetic acid	25	0.005–0.0006	375	2.15×10^{-4}	(394, 579)
$C_{11}H_{13}NO_3$	Acetyl-*p*-tolylaminoacetic acid	25	0.005–0.0012	375	2.15×10^{-4}	(579)
$C_{11}H_{13}NO_3$	2-Methylbenzoylaminopropionic acid	25	0.002–0.0006	375	1.63×10^{-4}	(200)
$C_{11}H_{13}NO_3$	4-Methylbenzoylaminopropionic acid	25	0.002–0.0006	375	1.67×10^{-4}	(200)
$C_{11}H_{13}NO_3$	*o*-Tolylsuccinamic acid	25	0.016–0.001	376	2.04×10^{-5}	(436)
$C_{11}H_{13}NO_3$	*p*-Tolylsuccinamic acid	25	0.004–0.001	376	1.89×10^{-5}	(436)
$C_{11}H_{13}NO_4$	1-Monomethyl 2-dimethylamino-terephthalate	25	0.03–0.001	376	$[4 \times 10^{-6}]$	(601)
$C_{11}H_{13}NO_4$	4-Monomethyl 2-dimethylamino-terephthalate	25	0.03–0.001	376	$[3 \times 10^{-7}]$	(601)
$C_{11}H_{13}NO_4$	1-Monomethyl 4-dimethylamino-isophthalate	25	0.0025–0.0006	376	5.5×10^{-7}	(601)
$C_{11}H_{13}NO_4$	3-Monomethyl 4-dimethylamino-isophthalate	25	0.002–0.0005	376	2.7×10^{-5}	(601)
$C_{11}H_{13}NO_4$	β-Monoethyl α, α'-dimethylcin-chomeronate	25	0.01–0.0012	375	1.8×10^{-5}	(413)
$C_{11}H_{13}NO_4$	γ-Monoethyl α, α'-dimethylcin-chomeronate	25	0.01–0.0012	375	2.1×10^{-5}	(413)
$C_{11}H_{13}NO_4$	*o*-Tolyliminodiacetic acid	25	0.005–0.001	374	2.0×10^{-3}	(579)
$C_{11}H_{13}NO_4$	*p*-Tolyliminodiacetic acid	25	0.003–0.0015	374	1.4×10^{-3}	(579)
$C_{11}H_{14}O_2$	2, 3, 4, 5-Tetramethylbenzoic acid	25	0.0005	375	6×10^{-5}	(451)
$C_{11}H_{14}O_2$	2, 3, 4, 6-Tetramethylbenzoic acid	25	0.0005	375	1×10^{-4}	(451)
$C_{11}H_{14}O_2$	2, 3, 5, 6-Tetramethylbenzoic acid	25	0.001–0.0005	375	3×10^{-4}	(451)
$C_{11}H_{14}O_2$	*p*-Thymotic aldehyde	25	0.0002–0.0001	375	1×10^{-4}	(204)
$C_{11}H_{14}O_3$	α-Ethyl-β-phenyl-β-hydroxypropionic acid	25	0.03–0.001	374	3.04×10^{-5}	(550)
$C_{11}H_{14}O_3$	Mesityleneglycolic acid	25	0.04–0.005	375	2.1×10^{-4}	(69)
$C_{11}H_{14}O_3$	α-Phenoxyisovaleric acid	25	(?)	(?)	4.66×10^{-4}	(57)
$C_{11}H_{14}O_3$	Phenylhydroxypivalic acid	25	0.03–0.001	374	4.5×10^{-5}	(550)
$C_{11}H_{14}O_3$	Phenylpropoxyacetic acid	25	0.04–0.0012	374	4.9×10^{-4}	(195)
$C_{11}H_{14}O_4$	3, 4-Diethoxybenzoic acid	25	0.001	375	3.32×10^{-5}	(436)
$C_{11}H_{15}NO_2$	α-*o*-Toluidinobutyric acid	25	0.005–0.0012	372	5.2×10^{-5}	(579)
$C_{11}H_{15}NO_2$	α-*p*-Toluidinobutyric acid	25	0.004–0.001	372	1.02×10^{-5}	(579)
$C_{11}H_{15}NO_2$	α-*o*-Toluidinoisobutyric acid	25	0.005–0.0012	372	4.8×10^{-6}	(579)
$C_{11}H_{15}NO_2$	β-*o*-Toluidinoisobutyric acid	25	0.005–0.0012	372	3.9×10^{-6}	(579)
$C_{11}H_{15}NO_2$	α-*p*-Toluidinoisobutyric acid	25	0.005–0.0012	372	6.6×10^{-6}	(579)
$C_{11}H_{15}NO_2$	β-*p*-Toluidinoisobutyric acid	25	0.005–0.0012	372	4.0×10^{-7}	(579)
$C_{11}H_{15}NO_4S$	Pseudocumenesulfoneaminoacetic acid	25	0.006–0.001	372	2.44×10^{-4}	(358)
$C_{11}H_{15}NO_4S$	*m*-Xylenesulfoneaminopropionic acid	25	0.008–0.001	372	2.40×10^{-4}	(358)
$C_{11}H_{16}O_3$	*d*-Camphorcarboxylic acid	25	0.016–0.001	375	1.74×10^{-4}	(136, 436)
$C_{11}H_{16}O_3$	*l*-Camphorcarboxylic acid	25	0.03–0.0012	375	1.74×10^{-4}	(136)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{11}H_{16}O_4$	3-Methylcyclohexylidenesuccinic acid	[25]	(?)	(?)	2.08×10^{-4}	(531)
$C_{11}H_{16}O_8$	2, 6-Dimethylpentane-2, 6-tetracarboxylic acid	25	0.06–0.004	373	3.7×10^{-3}	(582)
$C_{11}H_{17}N$	Diethylbenzylamine	25	0.008–0.002	222	3.0×10^{-5}	(207)
$C_{11}H_{17}NO_3$	Methyl 2-hydroxytrimethylammoniumbenzoate	1.2	0.016	(?)	$\Lambda_{0.016} = 134$	(140)
$C_{11}H_{18}O_4$	Cycloheptane-1, 1-diacetic acid	25	0.004–0.001	(?)	3.95×10^{-4}	(525.2)
$C_{11}H_{18}O_4$	Mono-*allo*-methyl *d*-camphorate	25	0.005–0.0012	376	1.06×10^{-5}	(583)
$C_{11}H_{18}O_4$	Mono-*o*-methyl *d*-camphorate	25	0.009–0.001	376	7.78×10^{-6}	(583)
$C_{11}H_{18}O_6$	*sym.*-Tetramethyl-β-acetoxyglutaric acid	25	0.03–0.0016	375	5.2×10^{-5}	(402)
$C_{11}H_{19}N_3O_5$	Antipeptone (β)	[25]	0.12–0.002	(?)	$\Lambda_{0.06} = 14.1$	(420)
$C_{11}H_{20}O_4$	2, 6-Diethylpimelic acid	25	0.007–0.0008	373	3.40×10^{-5}	(582)
$C_{11}H_{20}O_4$	β, β-Dipropylglutaric acid	25	0.002–0.0005	(?)	3.4×10^{-4}	(525.2)
$C_{11}H_{20}O_4$	Monomethyl *cis-sym.*-diisopropylsuccinate	25	0.004–0.0005	374	1.15×10^{-4}	(96)
$C_{11}H_{20}O_4$	Monomethyl *trans-sym.*-diisopropylsuccinate	25	0.003–0.0003	374	6.3×10^{-5}	(96)
$C_{11}H_{20}O_4$	α, α-Dimethyl-α′-isoamylsuccinic acid	25	0.008–0.001	375	6.1×10^{-4}	(97)
$C_{11}H_{20}O_4$	Octylmalonic acid	25	0.002–0.0003	375	9.2×10^{-4}	(524)
$C_{11}H_{22}O_3$	α-Dimethyl-β-hydroxypelargonic acid	25	0.008–0.0005	374	1.8×10^{-5}	(550)
$C_{11}H_{22}O_6$	Tetramethyl-α-methylglucoside	25	0.5	(?)	$\Lambda_{0.5} = 0.014$	(71)
$C_{11}H_{22}O_6$	Tetramethyl-β-methylglucoside	25	0.5	(?)	$\Lambda_{0.5} = 0.038$	(71)
$C_{12}H_6O_{12}$	Mellitic acid	25	0.014–0.0004	(?)	$\Lambda_{0.014} = 450$	(49); *cf.* (45)
$C_{12}H_8N_2O_4$	3, 2′-Dipyridyl-2, 3′-dicarboxylic acid	25	0.008–0.0005	376	3.1×10^{-4}	(436)
$C_{12}H_9NO_2$	3-Phenylpyridinecarboxylic acid	25	0.008–0.001	376	4×10^{-6}	(436)
$C_{12}H_9N_3S$	Thionine	25	0.004	(?)	$\Lambda_{0.004} > 17.7$	(230)
$C_{12}H_{10}N_2O$	*p*-Oxyazobenzene	25	0.0009	(?)	$\Lambda_{0.0009} = 1.1$	(179)
$C_{12}H_{11}IO$	Diphenyliodonium hydroxide	25	0.03–0.004	(?)	$\Lambda_{0.03} = 198$	(539)
$C_{12}H_{11}NO_2$	α-Naphthylaminoacetic acid	25	0.001–0.0005	373	3.2×10^{-5}	(579)
$C_{12}H_{11}NO_2$	β-Naphthylaminoacetic acid	25	0.002–0.001	373	5.5×10^{-5}	(579)
$C_{12}H_{12}O_2$	Phenyldihydroresorcinol	25	0.002–0.0005	376	1.14×10^{-5}	(508)
$C_{12}H_{12}O_4$	Benzylglutaconic acid	25	0.06–0.0009	377	1.50×10^{-4}	(577)
$C_{12}H_{12}O_4$	γ-Methyl-γ-phenylitaconic acid	25	0.016–0.001	376	1.97×10^{-4}	(529)
$C_{12}H_{12}O_4$	γ-Methyl-γ-phenylisoitaconic acid	25	0.017–0.0005	376	2.31×10^{-4}	(524, 529)
$C_{12}H_{12}O_4$	γ-Methylene-γ-phenylpyrotartaric acid	25	0.016–0.001	376	1.91×10^{-4}	(529)
$C_{12}H_{12}O_5$	α-Keto-γ-phenyladipic acid	25	0.03–0.004	375	8.9×10^{-3}	(156)
$C_{12}H_{12}O_6$	Benzylethenyltricarboxylic acid	25	0.03–0.016	375	3.0×10^{-2}	(578)
$C_{12}H_{12}O_8$	Diacetyldiketohexamethylenedicarboxylic acid	[25]	0.001–0.0005	(?)	$\Lambda_{0.001} = 343$	(184)
$C_{12}H_{13}NO_5$	α-Monomethyl benzoylaminosuccinate	25	0.03–0.002	376	1.85×10^{-4}	(442)
$C_{12}H_{13}NO_5$	β-Monomethyl benzoylaminosuccinate	25	0.016–0.002	376	4.9×10^{-4}	(442)
$C_{12}H_{13}NO_6$	α-Ethyl 2, 4-dimethylpyridinetricarboxylate	25	0.03–0.0005	(?)	$\Lambda_{0.03} = 263.6$	(320)
$C_{12}H_{13}NO_6$	β-Ethyl 2, 4-dimethylpyridinetricarboxylate	25	0.03–0.0005	(?)	$\Lambda_{0.03} = 277.9$	(320)
$C_{12}H_{13}N_3O_3$	Ethyl 1-*p*-tolyl-5-hydroxy-1, 2, 3-triazole-4-carboxylate	25	0.006–0.0014	374	1.0×10^{-2}	(158)
$C_{12}H_{14}O_3$	β-Phenyl-γ-acetylbutyric acid	25	0.03–0.0005	375	3.13×10^{-5}	(508)
$C_{12}H_{14}O_4$	Ethylbenzylmalonic acid	25	0.03–0.004	376	1.4×10^{-2}	(577)
$C_{12}H_{14}O_4$	*meso-sym.*-Methylbenzylsuccinic acid	25	0.03–0.002	376	2.42×10^{-4}	(577)
$C_{12}H_{14}O_4$	*p-sym.*-Methylbenzylsuccinic acid	25	0.03–0.002	376	2.14×10^{-4}	(577)
$C_{12}H_{14}O_6$	1-Monoethyl hemipinate	25	0.005–0.0007	375	1.45×10^{-4}	(597)
$C_{12}H_{14}O_6$	2-Monoethyl hemipinate	25	0.007–0.0009	375	1.0×10^{-4}	(597)

℄-Table.—The ℄-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{12}H_{15}NO_3$	α-Acetylanilinobutyric acid	25	0.003–0.008	371	1.05×10^{-4}	(579)
$C_{12}H_{15}NO_3$	β-Acetylanilinoisobutyric acid	25	0.003–0.0009	371	2.7×10^{-5}	(579)
$C_{12}H_{15}NO_3$	α-Acetyl-*o*-toluidinopropionic acid	25	0.003–0.0008	371	1.02×10^{-4}	(579)
$C_{12}H_{15}NO_3$	α-Acetyl-*p*-toluidinopropionic acid	25	0.003–0.0008	371	1.02×10^{-4}	(579)
$C_{12}H_{15}NO_4$	Cotarnine	0	0.008–0.001	134	$\Lambda_{0.008} = 53.5$	(241)
		25	0.008–0.001	226	$\Lambda_{0.008} = 124$	(241)
$C_{12}H_{16}O_3$	α-Isopropyl-β-phenyl-β-hydroxypropionic acid	25	0.03–0.0009	374	5.60×10^{-5}	(550)
$C_{12}H_{20}O_4$	Mono-*o*-ethyl *l*-isocamphorate	25	0.004–0.002	375	6.4×10^{-6}	(593)
$C_{12}H_{20}O_6$	α, γ-Diisopropyltricarballylic acid (M. P., 156°)	25	0.01–0.0013	374	1.62×10^{-3}	(98)
$C_{12}H_{20}O_6$	α, γ-Diisopropyltricarballylic acid (M. P., 173°)	25	0.006–0.0008	374	1.92×10^{-3}	(98)
$C_{12}H_{21}NO$	Triethylphenylammonium hydroxide	25	0.06–0.004	228	$\Lambda_{0.06} = 192$	(433)
$C_{12}H_{22}O_4$	*cis-sym.*-Diisobutylsuccinic acid	25	0.0015–0.0004	375	5.5×10^{-4}	(97)
$C_{12}H_{22}O_4$	*trans-sym.*-Diisobutylsuccinic acid	25	0.001–0.0002	375	2.24×10^{-4}	(97)
$C_{12}H_{22}O_4$	Monoethyl sebacate	25	0.002–0.0005	374	1.42×10^{-5}	(582)
$C_{12}H_{22}O_4$	Tetraethylsuccinic acid	25	0.0011	374	4.4×10^{-4}	(592)
$C_{12}H_{22}O_{11}$	Saccharose	25	2.0–0.02	(?)	$\Lambda_{0.05} = 0.030$	(71, 210)
$C_{12}H_{27}N$	Triisobutylamine	25	0.002–0.001	220	2.1×10^{-4}	(104)
$C_{13}H_9N$	Acridine	0	0.008	(?)	$\Lambda_{0.008} = 24$	(241)
$C_{13}H_9NO_4$	α-Phenylpyridinedicarboxylic acid	25	0.008–0.0005	376	1.2×10^{-4}	(436)
$C_{13}H_9NO_4$	β-Phenylpyridinedicarboxylic acid	25	0.016–0.0005	376	1.08×10^{-4}	(436)
$C_{13}H_{11}NO_2$	Phenyldihydroresorcylic acid nitrile	25	0.003–0.0003	376	1.95×10^{-4}	(508)
$C_{13}H_{12}O_6$	Mesitylenediglyoxylic acid	25	0.03–0.001	376	$\Lambda_{0.03} = 261$	(105)
$C_{13}H_{15}NO_5$	*eso*-Monoethyl acetylphenylglycine-*o*-carboxylate	25	0.014–0.0009	374	3.03×10^{-4}	(394)
$C_{13}H_{15}NO_5$	*exo*-Monoethyl acetylphenylglycine-*o*-carboxylate	25	0.03–0.0016	374	3.75×10^{-4}	(394)
$C_{13}H_{16}O_4$	Dimethylbenzylsuccinic acid	25	0.016–0.002	376	4.46×10^{-4}	(577)
$C_{13}H_{16}O_4$	*meso*-Ethylbenzylsuccinic acid	25	0.03–0.002	376	4.06×10^{-4}	(577)
$C_{13}H_{16}O_4$	*para*-Ethylbenzylsuccinic acid	25	0.016–0.001	376	2.57×10^{-4}	(577)
$C_{13}H_{16}O_4$	Methylbenzylglutaric acid	25	0.03–0.002	376	5.7×10^{-5}	(60)
$C_{13}H_{16}O_6$	1-Monopropyl hemipinate	25	0.004–0.001	374	9.2×10^{-4}	(598)
$C_{13}H_{16}O_6$	2-Monopropyl hemipinate	25	0.002–0.001	374	1.43×10^{-4}	(598)
$C_{13}H_{17}NO_3$	α-Acetyl-*p*-toluidinobutyric acid	25	0.003–0.0008	371	1.05×10^{-4}	(579)
$C_{13}H_{17}NO_3$	α-Acetyl-*p*-toluidinoisobutyric acid	25	0.004–0.0009	371	9.3×10^{-5}	(579)
$C_{13}H_{17}NO_3$	β-Acetyl-*p*-toluidinoisobutyric acid	25	0.003–0.0007	371	2.24×10^{-5}	(579)
$C_{13}H_{17}NO_3$	α-Acetyl-*o*-toluidinobutyric acid	25	0.004–0.001	371	9.0×10^{-5}	(579)
$C_{13}H_{17}NO_3$	β-Acetyl-*o*-toluidinoisobutyric acid	25	0.002–0.001	371	2.0×10^{-5}	(579)
$C_{13}H_{20}O_8$	Diethylpentanetetracarboxylic acid	25	0.09–0.01	373	2.1×10^{-2}	(582)
$C_{13}H_{24}O_4$	2, 6-Dipropylpimelic acid	25	0.001–0.0002	373	3.2×10^{-5}	(582)
$C_{13}H_{24}O_4$	2, 6-Diisopropylpimelic acid	25	0.004–0.0005	373	3.2×10^{-5}	(582)
$C_{14}H_9BrO_3S$	10-Bromophenanthrene-3(or 6)-sulfonic acid	18	0.5–0.0002	(?)	$\Lambda_{0.06} = 220$	(503)
$C_{14}H_{10}O_3$	Fluorene-9-hydroxy-9-carboxylic acid	25	0.01–0.0003	376	1.18×10^{-3}	(67)
$C_{14}H_{10}O_3$	*o*-Benzoylbenzoic acid	25	0.001–0.0002	376	3.7×10^{-4}	(397)
$C_{14}H_{10}O_3$	Diphenyleneglycolic acid	25	0.008–0.001	375	9.8×10^{-4}	(358)
$C_{14}H_{10}O_3S$	Phenanthrene-3-sulfonic acid	18	0.03–0.001	344	$\Lambda_{0.03} = 313$	(501)
$C_{14}H_{10}O_3S$	Phenanthrene-10-sulfonic acid	18	0.03–0.001	344	$\Lambda_{0.03} = 319$	(502)
$C_{14}H_{10}O_4$	Diphenic acid	25	0.008–0.0001	374	5×10^{-4}	(432)
$C_{14}H_{10}O_9$	α-Digallic acid	25	0.03–0.008	373	1.1×10^{-5}	(571)
$C_{14}H_{11}N$	Methylacridine	0	0.004	(?)	$\Lambda_{0.004} = 55$	(241)
$C_{14}H_{12}O_2$	Diphenylacetic acid	25	0.0004–0.0002	375	1.1×10^{-4}	(558)
$C_{14}H_{12}O_3$	Benzilic acid	25	0.02–0.0008	375	9.0×10^{-4}	(49, 67, 378)
		0–65	0.008–0.0005			(610, 611)
$C_{14}H_{12}O_9$(?)	Tannic acid	25	0.03–0.008	375	$\Lambda_{0.03} = 2.1$	(571)
$C_{14}H_{13}NO_2$	Methylphenyldihydroresorcylic acid nitrile	25	0.004–0.0002	373	2.0×10^{-4}	(508)

℄-Table.—The ℄-Arrangement.—*(Continued)*

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{14}H_{13}NO_3$	Acetyl-α-naphthylaminoacetic acid	25	0.004–0.0009	371	2.03×10^{-4}	(579)
$C_{14}H_{13}NO_3$	Acetyl-β-naphthylaminoacetic acid	25	0.002–0.001	371	2.36×10^{-4}	(579)
$C_{14}H_{13}NO_4$	α-Naphthyliminodiacetic acid	25	0.005–0.0012	371	5.0×10^{-4}	(579)
$C_{14}H_{13}NO_4$	β-Naphthyliminodiacetic acid	25	0.005–0.0012	371	2.3×10^{-3}	(579)
$C_{14}H_{15}NO_7$	Diethyl *o*-nitrobenzoylmalonate	25	0.001–0.0004	371	2.10×10^{-4}	(569)
$C_{14}H_{15}N_3O_3S$	*p*-Dimethylaminoazobenzenesulfonic acid	25	0.001–0.0002	371	$[3 \times 10^{-5}]$	(622)
$C_{14}H_{16}O_6$	Benzylisobutenyltricarboxylic acid	25	0.016–0.008	373	1.3×10^{-2}	(578)
$C_{14}H_{17}NO_6$	α, β-Diethyl 2, 4-dimethylpyridinetricarboxylate	25	0.016–0.001	371	1.8×10^{-2}	(320)
$C_{14}H_{18}O_3$	*dl*-Amylcoumaric acid	25	0.0001	374	1.3×10^{-5}	(488)
$C_{14}H_{18}O_3$	*dl*-Amylcoumarinic acd	25	0.0005	374	4.0×10^{-5}	(488)
$C_{15}H_{13}NO_4$	Phenyllutidinedicarboxylic acid	25	0.002–0.0005	376	1.15×10^{-4}	(436)
$C_{15}H_{13}NO_5$	Pyropapaveric acid	25	0.0013–0.0003	376	$\Lambda_{0.0013} = 101.0$	(49)
$C_{15}H_{14}N_2O_5$	Pyropapaveric acid ketoxime	25	0.0011–0.0006	376	3×10^{-5}	(49)
$C_{15}H_{16}O_4$	Ethyl phenyldihydroresorcylate	25	0.004–0.0004	375	6.05×10^{-5}	(508)
$C_{15}H_{20}O_3$	β-Phenyl-γ-trimethylacetylbutyric acid	25	0.002–0.0003	375	2.5×10^{-5}	(508)
$C_{16}H_{11}N_3O_4$	Diphenylvioluric acid	[25]	(?)	(?)	7.7×10^{-5}	(348)
$C_{16}H_{13}NO_7$	Papaveric acid	25	0.004–0.001	373	9×10^{-3}	(318, 436)
$C_{16}H_{13}NO_9S_3$	Phenyl-β-naphthylaminetrisulfonic acid	25	0.0013–0.00016	371	$\Lambda_{0.0013} = 351$	(165)
$C_{16}H_{14}N_2O_7$	Papaveric acid ketoxime	25	0.002–0.0005	(?)	$\Lambda_{0.002} = 406$	(49)
$C_{16}H_{14}O_2$	Diphenylcrotonic acid	25	0.002–0.001	375	8×10^{-5}	(188, 338)
$C_{16}H_{14}O_2$	β, γ-Diphenylvinylacetic acid	25	0.002–0.001	375	5.5×10^{-4}	(188, 338)
$C_{16}H_{14}O_4$	β-*para*-Diphenylsuccinic acid	25	0.0005–0.0002	375	2.2×10^{-4}	(577)
$C_{16}H_{14}O_4$	*sym.*-Diphenylsuccinic acid	25	0.02–0.0014	375	2.55×10^{-4}	(577)
$C_{16}H_{15}NO_4$	Monomethyl phenyllutidinedicarboxylate	25	0.008–0.001	376	4.5×10^{-5}	(436)
$C_{16}H_{16}O_2$	Dibenzylacetic acid	25	0.0005–0.0002	374	2.7×10^{-5}	(558)
$C_{16}H_{17}NO_3$	Acetyl-β-naphthylaminoisobutyric acid	25	0.0012–0.0006	371	2.16×10^{-5}	(579)
$C_{16}H_{19}N_3OS$	Tetramethylthionine hydroxide	0	0.002	133	$\Lambda_{0.002} = 99$	(230, 246)
		25	0.002	225	$\Lambda_{0.002} = 150$	(230, 246)
$C_{17}H_{12}O_2$	β-Chrysenic acid	25	0.0008–0.0003	375	9.0×10^{-4}	(601)
$C_{17}H_{15}NO_7$	β-Monomethyl papaverate	25	0.002–0.001	375	4×10^{-3}	(598); *cf.* (318)
$C_{17}H_{15}NO_7$	γ-Monomethyl papaverate	25	0.002–0.001	375	6×10^{-3}	(598); *cf.* (318)
$C_{17}H_{16}O_4$	Dibenzylmalonic acid	25	0.008–0.004	374	3.8×10^{-2}	(577)
$C_{17}H_{16}O_4$	Diphenylglutaric acid	25	0.003–0.0008	372	1.45×10^{-4}	(631)
$C_{17}H_{17}N_3$	Anilopyrine	18	0.05–0.001	(?)	$[\Lambda_{0.05} = 80]$	(401)
$C_{17}H_{19}NO_3$	Morphine	18	0.0005	(?)	$\Lambda_{0.0005} = 9.5$	(388)
		25	0.0006	(?)	$\Lambda_{0.0006} = 33$	(392)
$C_{17}H_{21}N_3$	Auramine G	0	0.001	(?)	$\Lambda_{0.001} = 30.6$	(246, 626)
		25	0.001	(?)	$\Lambda_{0.001} = 48.3$	(246, 626)
$C_{17}H_{21}N_3$	Auramine O	0	0.001	(?)	$\Lambda_{0.001} = 30.8$	(626)
		25	0.001	(?)	$\Lambda_{0.001} = 43.7$	(626)
$C_{17}H_{23}NO_3$	Atropine	25	0.005–0.0012	(?)	$\Lambda_{0.005} = 37$	(587)
$C_{17}H_{23}NO_3$	Hyoscyamine	25	0.01–0.0012	(?)	$[\Lambda_{0.01} = 19.3]$	(587)
$C_{18}H_{12}O_4$	Chrysodiphenic acid	25	0.0016–0.0004	375	1.6×10^{-3}	(601)
$C_{18}H_{14}O_8$	Dibenzoyltartaric acid	25	0.003–0.0008	374	$\Lambda_{0.0033} = 257$	(577)
$C_{18}H_{16}N_4O$	Phenosafranine	0	0.002	131	$\Lambda_{0.002} = 112$	(246)
		25	0.002	222	$\Lambda_{0.002} = 176$	(246)
$C_{18}H_{16}O_4$	γ-Benzylidene-γ-phenylpyrotartaric acid	25	0.016–0.004	373	1.18×10^{-4}	(532)
$C_{18}H_{16}O_4$	α-Truxillic acid	25	0.0002–0.0001	373	4.9×10^{-5}	(26)
$C_{18}H_{16}O_4$	γ-Truxillic acid	25	0.002–0.0005	373	1.05×10^{-4}	(26)
$C_{18}H_{19}N_3$	2, 5-Benzyliminopyrine	18	0.05–0.001	(?)	$\Lambda_{0.05} = 157$	(401)
$C_{18}H_{23}NO_4$	Methylmorphinium hydroxide	[25]	0.05	(?)	$[\Lambda_{0.05} = 5]$	(219)
$C_{19}H_{19}N_3O$	*p*-Triaminotriphenyl carbinol	0	0.002	(?)	$\Lambda_{0.002} > 85$	(246)
		25	0.002	220	$\Lambda_{0.002} > 135$	(246)
$C_{19}H_{22}N_2O$	Cinchonine	18	0.00007	194	1.2×10^{-6}	(388)
$C_{19}H_{36}O_4$	Cetylmalonic acid	25	0.004–0.0005	372	2.4×10^{-7}	(524)

C-Table.—The C-Arrangement.—(*Continued*)

Electrolyte		t, °C	c-Range	Λ_0	k(or Λ_c)	Lit.
Formula	Name					
$C_{20}H_{14}N_2O_7S_2$	α-Naphthaleneazo-β-naphtholdisulfonic acid	25	0.01–0.0006	(?)	$\Lambda_{0.01} = 344$	(445)
$C_{20}H_{17}NO$	Methylphenylacridinium hydroxide	0	0.004	(?)	$[\Lambda_{0.004} = 117]$	(241)
$C_{20}H_{21}NO_4$	Papaverine	18	0.00013	196	2.8×10^{-7}	(388)
		25	0.00016	222	$[5 \times 10^{-5}]$	(392)
$C_{20}H_{24}N_2O_2$	Quinine	18	0.0006	196	1.7×10^{-6}	(388)
		25	0.0007	222	$[1 \times 10^{-5}]$	(392)
$C_{21}H_{19}N_3O_4$	Pyropapaveric acid phenylhydrazone	25	0.001–0.0005	373	3.6×10^{-6}	(49)
$C_{21}H_{22}N_2O_2$	Strychnine	18	0.0002	195	8.5×10^{-7}	(388)
		25	0.0002	221	$[6 \times 10^{-5}]$	(392)
$C_{21}H_{24}O_4$	2, 6-Dibenzylpimelic acid	25	0.0005–0.0002	372	4.8×10^{-5}	(582)
$C_{21}H_{34}N_6O_9$	Pepsin fibrin peptone (α)	[25]	0.06–0.001	(?)	$\Lambda_{0.06} = 10.8$	(420)
$C_{22}H_{15}ClN_2O$	6-Chloro-*o*-*N*-phenylnaphthophenazonium hydroxide	0	0.002	(?)	$\Lambda_{0.002} > 110$	(246)
$C_{22}H_{16}N_3O$	Rosindulinium hydroxide	25	0.002	225	$\Lambda_{0.002} = 23.4$	(246)
$C_{22}H_{19}N_3O_6$	Papaveric acid phenylhydrazone	25	0.0005	373	4.5×10^{-3}	(49)
$C_{22}H_{23}NO_7$	Narcotine	18	0.00004	(?)	$\Lambda_{0.00004} = 8.5$	(388)
$C_{23}H_{20}O_6$	Methyl 3, 6-dimethoxyphenylxanthoniumcarboxylate	0	0.005	(?)	$\Lambda_{0.005} = 82$	(307, 409)
$C_{23}H_{26}N_2O_4$	Brucine	18	0.0013	194	1×10^{-6}	(388)
		25	0.0014–0.0007	220	6×10^{-6}	(392)
$C_{25}H_{31}N_3O$	Hexamethyl-*p*-triaminotriphenyl carbinol (crystal violet)	0	0.004–0.002	132	$\Lambda_{0.004} = 110$	(246)
		25	0.004	223	$\Lambda_{0.004} = 150$	(246)
$C_{26}H_{18}N_2O$	Phenylphenanthrophenazonium hydroxide	0	0.002	131	$\Lambda_{0.002} > 3.4$	(246)
$C_{26}H_{43}NO_6$	Glycocholic acid	25	0.0013–0.0006	367	1.3×10^{-4}	(91)
$C_{27}H_{34}N_2O$	Tetraethyldiaminotriphenyl carbinol (brilliant green)	0	0.004	(?)	$\Lambda_{0.004} = 24.3$	(246)
$C_{32}H_{24}N_6O_6S_2$	Congo blue	25	0.003–0.0004	(?)	$\Lambda_{0.003} = 13.0$	(89)
$C_{32}H_{48}O_{16}$	Polymethacrylic acid	25	0.03–0.0005	367	3.5×10^{-3}	(405)
$C_{37}H_{31}N_3O_{10}S_3$	Triphenyl-*p*-rosanilinetrisulfonic acid	18	0.0025–0.0006	(?)	$\Lambda_{0.0025} = 556$	(324)
		90	0.0025–0.0006	(?)	$\Lambda_{0.0025} = 1156$	(324)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abati, *36*, **36 II:** 834; 06. (2) Abati, *36*, **38 I:** 152; 08. (3) Abati and Solimene, *36*, **38 II:** 577; 08. (4) Abbott and Bray, *1*, **31:** 729; 09. (5) Abegg, Fox and Herz, *93*, **35:** 129; 03. (6) Acree and Shadinger, *11*, **39:** 124; 08. (7) Angeli, *36*, **22 II:** 1; 92. (8) Angeli and Rimini, *36*, **26 II:** 34; 96. (9) Anschütz, *13*, **353:** 139; 07.

(10) Anschütz and Motschmann, *13*, **392:** 100; 12. (11) Arrhenius, *7*, **4:** 96; 89. (12) Arrhenius, *7*, **5:** 1; 90. (13) Aschan, *13*, **271:** 231; 92. (14) Askenasy and Meyer, *25*, **26:** 1354; 93. (15) Asriel, *Diss.*, Heidelberg, 1900. (16) Auerbach, *7*, **49:** 217; 04. (17) Auerbach and Zeglin, *7*, **103:** 178; 23. (18) Auld and Hantzsch, *25*, **38:** 2677; 05. (19) Auwers, *13*, **285:** 241; 95.

(20) Auwers, *13*, **292:** 132; 96. (21) Auwers, *13*, **298:** 147; 97. (22) Auwers and Campenhausen, *25*, **29:** 1543; 96. (23) Auwers and Jacob, *25*, **27:** 1114; 94. (24) Auwers, Köbner and Meyenburg, *25*, **24:** 2887; 91. (25) Auwers and Oswald, *13*, **285:** 283; 95. (26) Bader, *7*, **6:** 289; 90. (27) Baeyer, *13*, **269:** 145; 92. (29) Bailey and Mikeska, *1*, **38:** 1771; 16.

(30) Balbiano, *36*, **29 II:** 490; 99. (31) Bamberger, *25*, **27:** 359; 94. (32) Bamberger, *25*, **35:** 3697; 02. (33) Bamberger and Berlé, *13*, **273:** 303; 93. (34) Bamberger and Lodter, *13*, **288:** 74; 95. (35) Barmwater, *7*, **45:** 557; 03. (37) Barmwater, *7*, **56:** 225; 06. (39) Barth, *7*, **9:** 176; 92.

(40) Baur, *13*, **296:** 95; 97. (42) Baur, *7*, **18:** 182; 95. (43) Baur, *7*, **23:** 409; 97. (44) Bayliss, *289*, **36:** 221; 08. (45) Berthelot, *6*, **23:** 5; 91. (46) Berthelot, *6*, **24:** 5; 91. (47) Berthelot, *34*, **110:** 703; 90. (48) Berthelot, *34*, **112:** 287; 91. (49) Bethmann, *7*, **5:** 385; 90.

(50) Bichat, *Bull. Soc. Nancy*, (2) **11**, *Bull. des Séances*, **7°**, 16 (1891). (51) Billmann, *25*, **43:** 568; 10. (52) Billmann and Bjerrum, *25*, **49:** 2515; 16. (53) Billitzer, *57*, **20:** 666; 99. (54) Bischoff, *25*, **24:** 1064; 91. (55) Bischoff, *25*, **24:** 2001; 91. (56) Bischoff, *25*, **33:** 924; 00. (57) Bischoff, *25*, **33:** 931; 00. (58) Bischoff and Jaunsnicker, *25*, **23:** 3399; 90. (59) Bischoff and Mintz, *25*, **23:** 3410; 90.

(60) Bischoff and Walden, *25*, **23:** 1950; 90. (61) Bischoff and Walden, *25*, **26:** 1452; 93. (62) Bleekrode, *3*, **5:** 375; 78. (63) Bock, *8*, **30:** 631; 87. (64) Böeseken and Couvert, *70*, **29:** 275; 10. (65) Böeseken, *70*, **34:** 96; 15. (66) Böeseken, Ruys and Brackmann, *70*, **34:** 272; 15. (67) Böeseken, *70*, **35:** 211; 15. (68) Böeseken, *70*, **39:** 178; 20. (69) Böeseken and Felix, *70*, **40:** 568; 21.

(70) Böeseken, Anema and Brevet, *70*, **41:** 778; 22. (70.5) Böeseken and Coops, *64V*, **29:** 368; 20. (71) Böeseken and Couvert, *70*, **40:** 354; 21. (72) Böeseken and Dujardin, *70*, **32:** 97; 13. (73) Böeseken and van der Ent, *70*, **37:** 178; 18. (74) Böeseken and van Giffen, *70*, **39:** 183; 20. (75) Böeseken and de Graaff, *70*, **41:** 199; 22. (76) Böeseken, Hansen and Bertram, *70*, **35:** 309; 16. (77) Böeseken and Hermans, *70*, **42:** 1104; 23. (78) Böeseken and van der Hoek Ostende, *70*, **37:** 162; 18. (79) Böeseken and Kalshoven, *70*, **37:** 130; 18.

(80) Böeseken and van Lennep, *70*, **31:** 196; 12. (81) Böeseken and Ouwehand, *70*, **40:** 574; 21. (82) Böeseken and van Rossem, *70*, **30:** 392; 11. (83) Böeseken and Rost van Touningen, *70*, **39:** 187; 20. (84) Böeseken, Schweizer and van der Want, *70*, **31:** 86; 12. (85) Böeseken, Sturm and Goettsch, *70*, **37:** 144; 18. (86) Böeseken and Verkade, *70*, **36:** 167; 16. (87) Böeseken and Voogd, *70*, **42:** 745; 23. (88) Böeseken, Weisfelt, Spek, Loon and Goettsch, *70*, **37:** 165; 18. (89) Bogoiavlenski, *53*, **44:** 1813; 12.

(90) Bollemont, *27*, **25:** 28; 01. (91) Bondi, *202*, **53:** 8; 07. (92) Bone and Henstock, *4*, **83:** 1380; 03. (93) Bone and Perkin, *4*, **67:** 108; 95. (94) Bone and Perkin, *4*, **67:** 416; 95. (95) Bone and Sprankling, *4*, **75:** 839; 99. (96) Bone and Sprankling, *4*, **77:** 654; 00. (97) Bone and Sprankling, *4*, **77:** 1298; 00. (98) Bone and Sprankling, *4*, **81:** 29; 02. (99) Bone and Sprankling, *4*, **83:** 1378; 03.

(100) Bone, Sudborough and Sprankling, *4*, **85:** 534; 04. (101) Bouty, *8*, **3:** 161; 78. (102) Boyle, *4*, **115:** 1505, 19. (102.1) Bradley and Lewis, *50*, **29:** 782; 25. (103) Bredig, *7*, **11:** 829; 93. (104) Bredig, *7*, **13:** 289; 94. (105) Breed, *Thesis*, Bryn Mawr, 1901. (107) Bruce, *1*, **26:** 449; 04. (108) Bruner, *9*, **19:** 861; 13. (109) Bruni, *9*, **14:** 701; 08.

(110) Bruni and Sandonnini, *9*, **16**: 223; 10. (111) Bruylanti and Stassens, *186*, **1921**: 702. (112) Buglia and Karczag, *22*, **18 II**: 374; 09. (113) Buglia and Karczag, *22*, **18 II**: 474; 09. (114) Bülow and Haas, *25*, **43**: 3401; 10. (115) Burke, *1*, **42**: 2500; 20. (116) Calcagni, *22*, **25 I**: 643; 16. (117) Caldwell, *5*, **78A**: 272; 06. (118) Carrara and Levi, *36*, **32 II**: 36; 02. (119) Carrara and Rossi, *36*, **27 II**: 505; 97.

(120) Carré, *27*, **33**: 1314; 05. (121) Chanoz, *Ann. Univ. Lyon*, **I**, Fasc. **18**: 1; 06. (122) Chavanne, *6*, **3**: 507; 04. (123) Chroustchoff, *34*, **108**: 1003; 89. (124) Claisen, *13*, **297**: 1; 97. (126) Clover and Jones, *11*, **43**: 187; 10. (127) Coffetti, *36*, **30 II**: 235; 00. (128) Collan, *7*, **10**: 130; 92. (129) Collie, *4*, **77**: 971; 00.

(130) Collie and Hilditch, *4*, **91**: 787; 07. (131) Collie and Tickle, *4*, **75**: 710; 99. (132) Constam and White, *11*, **29**: 1; 03. (134) Coos, *25*, **35**: 4109; 02. (135) Coppadoro, *36*, **32 I**: 537; 02. (136) Creighton, *7*, **81**: 543; 12. (137) Crossley and Perkin, *4*, **73**: 1; 98. (138) Crum Brown and Walker, *13*, **261**: 107; 91. (139) Crum Brown and Walker, *13*, **274**: 41; 93.

(140) Cumming, *7*, **57**: 574; 06. (141) Dalle, *70*, **21**: 123; 02. (142) van Dam, *176*, **7**: 1013; 10. (143) Da Monte and Zoso, *36*, **27 II**: 467; 97. (144) Davidson and Hantzsch, *25*, **31**: 1612; 98. (145) Dawson and Crann, *4*, **109**: 1262; 16. (146) Dawson and Reiman, *4*, **107**: 1426; 15. (147) Deakin and Rivett, *4*, **101**: 127; 12. (148) Dedichen, *25*, **39**: 1831; 06. (149) Déguisne, *Diss.*, Strasbourg, 1895.

(150) Derick and Hess, *1*, **40**: 537; 18. (151) Derick and Kamm, *1*, **39**: 388; 17. (152) Deschauer, *Diss.*, Heidelberg, 1905. (153) Deussen, *93*, **44**: 300; 05. (154) Devrient, *Diss.*, Leipzig, 1896. (155) Dieckmann, *25*, **53**: 1772; 20. (156) Dieckmann and Hardt, *25*, **52**: 1134; 19. (157) Dimroth, *13*, **335**: 1; 04. (158) Dimroth, *13*, **338**: 143; 05. (159) Dony-Hénault, *186*, **1909**: 342.

(160) Doroshevskii and Rozhdestvenskii, *53*, **40**: 887; 08. (161) van Dorssen, *70*, **29**: 368; 10. (162) Drucker, *7*, **49**: 563; 04. (163) Drucker, *7*, **52**: 641; 05. (164) Drushel and Felty, *12*, **43**: 64; 17. (165) Ebersbach, *7*, **11**: 608; 93. (166) Engler and Hantzsch, *25*, **33**: 2147; 00. (167) Enklaar, *70*, **24**: 419; 05. (168) Erlenmeyer, *25*, **42**: 2649; 09. (169) Erlenmeyer, *25*, **42**: 2655; 09.

(170) Esmann, *Diss.*, Leipzig, 1905. (171) Euler, *25*, **39**: 1607; 06. (172) Euler, *7*, **21**: 257; 96. (173) Euler and Bolin, *7*, **66**: 71; 09. (174) Euler and Euler, *19*, **1**: 111; 03. (175) Euler and Euler, *25*, **36**: 4253; 03. (176) Ewan, *4*, **69**: 96; 96. (177) Eykman, *25*, **24**: 1278; 91. (178) Fanjung, *7*, **14**: 673; 94. (179) Farmer and Hantzsch, *25*, **32**: 3089; 99.

(180) Farmer and Hantzsch, *25*, **32**: 3101; 99. (181) Feist, *13*, **257**: 253; 90. (182) Feist, *25*, **25**: 315; 92. (183) Feist, *25*, **26**: 747; 93. (184) Feist, *25*, **32**: 315; 99. (185) Fichter, *25*, **54**: 1280; 21. (186) Fichter and Beisswenger, *25*, **36**: 1200; 03. (187) Fichter and Gisiger, *25*, **42**: 4707; 09. (188) Fichter and Latzko, *52*, **74**: 327; 06. (189) Fichter and Obladen, *25*, **42**: 4703; 09.

(190) Fichter and Pfister, *13*, **334**: 201; 04. (191) Fichter and Probst, *13*, **372**: 69; 10. (192) Fichter and Schwab, *13*, **348**: 251; 06. (193) Fichter and Sonneborn, *25*, **35**: 938; 02. (194) Fierz-David and Wissenbach, *37*, **3**: 305; 20. (195) Findlay, Turner and Owen, *4*, **95**: 938; 09. (196) Fiorini, *36*, **31 I**: 33; 01. (197) Ford and Guthrie, *4*, **89**: 76; 06. (198) Foster, *2*, **8**: 257; 99.

(200) Franke, *7*, **16**: 463; 95. (201) Frazer, *11*, **30**: 309; 03. (202) Freundlich and Krestovnikoff, *7*, **76**: 79; 11. (203) Gerilowski and Hantzsch, *25*, **29**: 743; 96. (204) Glimm, *Diss.*, Freiburg, 1902. (205) Gnehm and Sheutz, *52*, **63**: 405; 01. (206) Goldschmidt, *93*, **28**: 97; 01. (207) Goldschmidt and Salcher, *7*, **29**: 89; 99. (208) Gorke, *7*, **61**: 495; 08. (209) Graul and Hantzsch, *25*, **31**: 2854; 98.

(210) Green, *4*, **93**: 2049; 08. (211) Grossmann and Krämer, *93*, **41**: 43; 04. (212) Gudzent, *7*, **60**: 25; 09. (213) Guinchant, *34*, **120**: 1220; 95. (214) Guinchant, *34*, **121**: 71; 95. (215) Guinchant, *Thesis*, Paris, 1897. *7*, **24**: 174; 97. (216) Guinchard, *25*, **32**: 1723; 99. (217) Guinchard, *Diss.*, Upsala, 1899. (218) Gutbier, *93*, **29**: 29; 04. (219) Hädrich, *7*, **12**: 476; 93.

(220) Haiser and Wenzel, *57*, **30**: 377; 09. (220.1) Halban and Ebert, *7*, **112**: 359; 24. (221) Hallwachs, *8*, **68**: 1; 99. (222) Hantzsch, *13*, **296**: 84, 111; 97. (223) Hantzsch, *25*, **22**: 2827; 89. (224) Hantzsch, *25*, **25**: 827; 92. (225) Hantzsch, *25*, **31**: 607; 99. (226) Hantzsch, *25*, **32**: 3066; 99. (227) Hantzsch, *25*, **35**: 265; 02. (228) Hantzsch, *25*, **36**: 2069; 03. (229) Hantzsch, *25*, **37**: 1076; 04.

(230) Hantzsch, *25*, **38**: 2143; 05. (231) Hantzsch, *25*, **39**: 139; 06. (232) Hantzsch, *25*, **39**: 3149; 06. (233) Hantzsch, *25*, **40**: 1523; 07. (234) Hantzsch, *25*, **40**: 1556; 07. (235) Hantzsch and Barth, *25*, **35**: 210; 02. (236) Hantzsch and Davidson, *25*, **29**: 1522; 96. (237) Hantzsch and Dollfus, *25*, **35**: 226; 02. (238) Hantzsch and Glover, *25*, **40**: 4344; 07. (239) Hantzsch and Holl, *25*, **34**: 3430; 01.

(240) Hantzsch and Isherwood, *25*, **42**: 986; 09. (241) Hantzsch and Kalb, *25*, **32**: 3109; 99. (242) Hantzsch and Kaufmann, *13*, **292**: 317; 96. (243) Hantzsch and Lehmann, *25*, **33**: 3668; 00. (244) Hantzsch and Miolati, *7*, **10**: 1; 92. (245) Hantzsch and Osswald, *25*, **32**: 641; 99. (246) Hantzsch and Osswald, *25*, **33**: 278; 00. (247) Hantzsch and Rinckenberger, *25*, **32**: 628; 99. (248) Hantzsch and Robinson, *25*, **43**: 92; 10. (249) Hantzsch and Schultze, *25*, **29**: 2251; 96.

(250) Hantzsch, Schümann and Engler, *25*, **32**: 1703; 99. (251) Hantzsch and Sebaldt, *7*, **30**: 258; 99. (252) Hantzsch and Sluiter, *25*, **39**: 162; 06. (253) Hantzsch and Vagt, *13*, **314**: 339; 01. (254) Hantzsch and Veit, *25*, **32**: 607; 99. (255) Hantzsch and Voegelen, *25*, **34**: 3142; 01. (256) Hantzsch and Voegelen, *25*, **35**: 1001; 02. (257) Hartley, Thomas and Applebey, *4*, **93**: 538; 08. (258) Heberlein, *Diss.*, Strasbourg, 1898. (259) Hedley, *Diss.*, Leipzig, 1908.

(260) Henrich, *25*, **37**: 1406; 04. (261) Henrich, *57*, **18**: 142; 97. (262) Henry, *7*, **10**: 96; 92. (263) Henstock and Sprankling, *4*, **91**: 354; 07. (264) Henstock and Woolley, *4*, **91**: 1954; 07. (265) Hicks, *4*, **113**: 554; 18. (266) Hill and Sirkar, *5*, **83A**: 130; 10. (267) His and Paul, *7*, **31**: 1; 00. (268) Hjelt, *25*, **25**: 488; 92. (269) Hjelt, *25*, **25**: 524; 92.

(270) Hjelt, *60*, **38**: 132; 95. (271) de Hlasko, *42*, **20**: 167; 23. (273) van't Hoff and Reicher, *7*, **2**: 777; 88. (274) Hofmann, Ehrhart and Schneider, *25*, **46**: 1657; 13. (275) Holleman, *70*, **14**: 121; 95. (276) Holleman, *70*, **16**: 162; 97. (277) Holleman, *70*, **21**: 56; 02. (278) Holleman, *70*, **21**: 432; 02. (279) Holleman and De Bruyn, *70*, **20**: 360; 01.

(280) Holmberg and Mattisson, *13*, **353**: 123; 07. (281) Holmberg, *13*, **353**: 131; 07. (282) Holmberg, *13*, **359**: 81; 08. (283) Holmberg, *25*, **45**: 2997; 12. (284) Holmberg, *52*, **71**: 264; 05. (285) Holmberg, *52*, **75**: 169; 07. (286) Holmberg, *52*, **79**: 253; 09. (287) Hörcher, *Diss.*, Budapest, 1911. (288) van Hove, *186*, **1909**: 282. (289) Howles and Thorpe, *182*, **15**: 103; 99.

(290) Hufferd and Noyes, *1*, **43**: 925; 21. (291) Inglis and Knight, *4*, **93**: 1595; 08. (292) Jacob, *Diss.*, Heidelberg, 1894. (293) Jahn, *7*, **16**: 72; 95. (294) James, *4*, **103**: 1368; 13. (295) Jellinek, *7*, **76**: 257; 11. (296) Johnston, *25*, **37**: 3625; 04. (297) Johnston, *7*, **57**: 557; 06. (298) Jones and Getman, *11*, **32**: 308; 04. (299) Jones and Jacobson, *11*, **40**: 355; 08.

(300) Jones and West, *11*, **34**: 357; 05. (301) Joyner, *93*, **77**: 103; 12. (302) Kamm and McClugage, *1*, **38**: 419; 16. (303) Kanitz, *278*, **118**: 539; 07. (304) Kanitz, *202*, **47**: 476; 06. (305) Kanolt, *1*, **29**: 1402; 07. (307) Kehrmann, *13*, **372**: 287; 10. (308) Kendall, *1*, **36**: 1069; 14.

(310) Kendall, *1*, **38**: 1480; 16. (311) Kendall, *1*, **39**: 7; 17. (312) Kendall, *4*, **101**: 1275; 12. (313) Kendall, *147*, **2**: No. 38; 13. (314) Kendall, *5*, **85**: 200; 11. (315) Kerp and Baur, *291*, **26**: 231; 07. (316) Kerp and Baur, *291*, **26**: 297; 07. (317) Kipping, *4*, **67**: 139; 95. (318) Kirpal, *57*, **18**: 461; 97. (319) Kirpal, *57*, **28**: 439; 07.

(320) Kirpal and Reiman, *57*, **38**: 249; 17. (321) Klarmann, *93*, **132**: 289; 24. (322) Klason and Carlson, *25*, **39**: 732; 06. (323) Klemenc and Müller, Univ. Vienna, *0*. (324) Knecht and Batey, *290*, **25**: 194; 09. (325) Knox, *8*, **54**: 44; 95. (326) Kohlrausch, *8*, **159**: 233; 76. (327) Konowalow, *8*, **49**: 733; 93. (328) Kortright, *11*, **18**: 365; 96. (329) Kraemer, *Diss.*, Münster, 1904.

(330) Kruyt, *64V*, **22**: 695; 14. (331) Kühling, *25*, **38**: 1638; 05. (332) Kuriloff, *7*, **23**: 90; 97. (333) Küster, *13*, **315**: 174; 01. (334) Küster, *13*, **345**: 1; 06. (335) Küster, *13*, **346**: 1; 06. (336) Küster, *25*, **35**: 1268; 02. (337) Küster, *25*, **35**: 2948; 02. (338) Latzko, *Diss.*, Basel, 1904. (339) Levi, *36*, **31 II**: 1; 01.

(340) Ley, *25*, **42**: 354; 09. (341) Ley and Euler, *9*, **13**: 797; 07. (342) Ley and Hantzsch, *25*, **39**: 3149; 06. (343) Ley and Schaefer, *7*, **42**: 690; 03. (344) Lichty, *13*, **319**: 369; 01. (345) Liebermann, *25*, **24**: 1101; 91. (346) Liebermann, *25*, **28**: 129; 95. (347) Liebermann, *25*, **36**: 176; 03. (348) Lifschitz, *25*, **46**: 3233; 13. (349) Lindet, *34*, **138**: 508; 04.

(350) Locke, *1*, **46**: 1246; 24. (351) Loomis, *8*, **60**: 523; 97. (352) Loomis, *8*, **60**: 547; 97. (353) Loomis, *2*, **4**: 252; 96. (354) Loomis, *2*, **4**: 273; 97. (355) Lorenz and Brehmer, *93*, **128**: 76; 23. (356) Lorenz and Schmidt, *93*, **111**: 175; 20. (357) Lovén, *7*, **13**: 550; 94. (358) Lovén, *7*, **19**: 456; 96. (359) Lovén and Ahlberg, *25*, **54**: 227; 21.

(360) Lucas, *25*, **32**: 3179; 99. (361) Lumsden, *4*, **87**: 90; 05. (362) Lundén, *42*, **5**: 145; 07. (363) Lundén, *42*, **5**: 574; 07. (365) Lundén, *42*, **8**: 331; 10. (366) Lundén, *7*, **54**: 532; 06. (367) Lundén, *7*, **70**: 249; 10. (368) Luther, *9*, **13**: 294; 07. (369) Lutz, *25*, **35**: 2460; 02.

(370) Lutz, *25*, **35**: 2549; 02. (371) Lutz, *25*, **35**: 4369; 02. (372) Maas, *Diss.*, München, 1909. (373) Mackay, *232*, **11**: 324; 06. (374) Magidson and Gorbachov, *25*, **56**: 1810; 23. (375) Magnanini, *36*, **20**: 453; 90. (376) Magnanini, *36*, **21 II**: 215; 91. (378) Magnanini, *36*, **23 I**: 197; 93. (379) Magnanini, *36*, **26 II**: 92; 96.

(380) Magnanini, *7*, **12**: 56; 93. (381) Magnanini and Scheidt, *36*, **22 I**: 436; 92. (383) Maltby, *7*, **18**: 133; 95. (384) Mamcli, *36*, **41 I**: 294; 11. (385) Manasse and Rupe, *25*, **27**: 1818; 94. (386) Marcilly, *27*, **31**: 119; 04. (387) Marqueyrol and Carré, *27*, **27**: 199; 20. (388) Mauz, *Diss.*, Tübingen, 1904. (389) McKenzie, *4*, **75**: 753; 99.

(390) Meldrum, *50*, **15**: 474; 11. (391) Mellor, *4*, **79**: 126; 01. (392) Mennicke, *Diss.*, Leipzig, 1897. (393) van der Meulen, *Diss.*, Basel, 1896. (394) Meusel, *Diss.*, Breslau, 1900. (395) Meyer, *25*, **36**: 3599; 03. (396) Meyer, *25*, **44**: 2966; 11. (397) Meyer, *57*, **28**: 1231; 07. (398) Meyer, *9*, **13**: 494; 07. (399) Meyer, *9*, **17**: 976; 11.

(400) Michael and Bunge, *25*, **41**: 2907; 08. (401) Michaelis, *13*, **339**: 117; 05. (402) Michajlenko, *53*, **30**: 466; 98. (403) Michajlenko and Javorskii, *53*, **32**: 328; 00. (404) Miolati and Bellucci, *93*, **26**: 209; 01. (405) Mjöen, *25*, **30**: 1227; 97. (406) Moest, *Diss.*, Basel, 1899. (407) Moureu and Boutaric, *42*, **18**: 348; 20. (408) Mühlhauser, *Diss.*, Basel, 1902. (409) Müller, *25*, **43**: 2609; 10.

(410) Muller, *27*, **27**: 1011; 02. (411) Muller and Bauer, *42*, **2**: 472; 04. (412) Mulliken, *Diss.*, Leipzig, 1890. (413) Mumm and Gottschaldt, *25*, **55**: 2064; 22. (414) Mündler, *Diss.*, Heidelberg, 1901. (415) Nasini and Costa, *22*, **1891**: 100. (416) Nasini and Pezzolato, *7*, **12**: 501; 93. (417) Naumann, *9*, **16**: 772; 10. (418) Neale, *83*, **17**: 505; 21. (419) Nernst and Hohmann, *7*, **11**: 352; 93.

(420) Neumann, *202*, **45**: 216; 05. (421) Noyes, *1*, **30**: 335; 08. (422) Noyes, *7*, **6**: 241; 90. (423) Noyes and Burke, *1*, **34**: 174; 12. (424) Noyes and Potter, *1*, **34**: 1067; 12. (425) Noyes and Sammet, *7*, **43**: 513; 03. (426) Oliveri-Mandalà, *36*, **40 I**: 102; 10. (427) Oliveri-Mandalà, *36*, **44 II**: 175; 14. (428) Oliveri-Mandalà, *36*, **45 I**: 303; 15. (429) Oliveri-Mandalà, *36*, **46 I**: 298; 16.

(430) Osaka, *7*, **35**: 661; 00. (431) Oslan, *Diss.*, Heidelberg, 1901. (432) Ostwald, *52*, **32**: 300; 85. (433) Ostwald, *52*, **33**: 352; 86. (434) Ostwald, *7*, **1**: 74; 87. (435) Ostwald, *7*, **2**: 270; 88. (436) Ostwald, *7*, **3**: 369; 89. (437) Ottén, *Diss.*, München, 1887. (438) Palomaa, *175*, **3A**: 1; 11. (439) Paul, *293*, **239**: 48; 01.

(440) Paul, *7*, **110**: 417; 24. (441) Pauly, Schübel and Lockemann, *13*, **383**: 288; 11. (442) Pauly and Weir, *25*, **43**: 661; 10. (443) von Pechmann, *25*, **33**: 3323; 00. (444) von Pechmann and Neger, *13*, **273**: 186; 93. (445) Pelet-Jolivet and Wild, *27*, **3**: 1087; 08. (446) Peratoner and Palazzo, *56*, **36 I**: 7; 06. (447) Perkin, *4*, **65**: 572; 94. (448) Perkin, *4*, **69**: 1457; 96. (449) Perkin and Simonsen, *4*, **91**: 840; 07.

(450) Petersen, *214*, **7**: 303; 90. (451) Pfaff, *Diss.*, Heidelberg, 1897. (452) Pfeiffer, *3*, **23**: 625; 84. (453) Philip, *4*, **93**: 925; 08. (454) Pick, *B13*, 374: 12. (455) Picton, *Diss.*, Leipzig, 1908. (456) Pilat, *Diss.*, Leipzig, 1905. (457) Pip, *Diss.*, Heidelberg, 1898. (458) Pomeranz, *57*, **18**: 575; 97. (459) Pope and Read, *4*, **105**: 811; 14.

(460) Pospischill, *25*, **31**: 1950; 98. (461) Protopopov and Reformatskii, *53*, **33**: 242; 01. (462) Pummerer and Hofmann, *25*, **56**: 1255; 23. (463) Quinet, *51*, **8**: 278; 09. (464) Rabe, *25*, **43**: 2964; 10. (465) Ramberg, *25*, **40**: 2588; 07. (466) Ramstedt, *147*, **3**: No. 7; 15. (467) Ray, De and Dhar, *4*, **103**: 1562; 13. (468) Ray and Dey, *4*, **111**: 510; 17. (469) Ray, Dey and Ghosh, *4*, **111**: 413; 17.

(470) Reformatskii, *25*, **28**: 3262; 95. (471) Reformatskii, *53*, **30**: 453; 98. (472) Rimbach and Neizert, *93*, **52**: 406; 07. (473) Rimbach and Weber, *7*, **51**: 473; 05. (474) Rivals, *6*, **12**: 501; 97. (475) Rivett and Sidgwick, *4*, **97**: 734; 10. (476) Rivett and Sidgwick, *4*, **97**: 1677; 10. (477) Robinson and Jones, *4*, **101**: 62; 12. (478) Rosenheim and Aron, *93*, **39**: 170; 04. (479) Rosenheim and Bertheim, *93*, **34**: 427; 03.

(480) Rosenheim and Grünbaum, *93*, **61**: 187; 09. (481) Rosenheim and Pinsker, *25*, **43**: 2003; 10. (482) Rosenheim and Stadler, *25*, **38**: 2687; 05. (483) Rosenheim and Weinheber, *93*, **69**: 261; 11. (484) Rosenmund and Pfannkuch, *25*, **55**: 2357; 22. (485) Ross, *292*, **11**: 95; 02. (486) Roth, *25*, **33**: 2032; 00. (487) Roth and Östling, *25*, **46**: 309; 13. (488) Roth and Stoermer, *25*, **46**: 260; 13. (489) Rothmund and Drucker, *7*, **46**: 827; 03.

(490) Rouche, *186*, No. **8**: 534; 21. (491) Rudorf, *7*, **43**: 257; 03. (492) Ruff, *25*, **32**: 550; 99. (493) Rupe, *13*, **256**: 1; 90. (494) Rupe, Ronus and Lotz, *25*, **35**: 4265; 02. (495) Ruppin, *7*, **14**: 467; 94. (496) Sackur, *7*, **38**: 129; 01. (497) Sakurai, *4*, **69**: 1654; 96. (498) Salway, *Diss.*, Leipzig, 1906. (499) Sandelin, *13*, **396**: 285; 13.

(500) Sandonnini, *9*, **16**: 227; 10. (501) Sandquist, *13*, **369**: 104; 09. (502) Sandquist, *13*, **392**: 76; 12. (503) Sandquist, *19*, **6**: No. 9; 16. (504) Sarow, *Diss.*, Berlin, 1905. (505) Schall, *7*, **14**: 701; 94. (506) Schaller, *7*, **25**: 497; 98. (507) Schilling, *Diss.*, Halle, 1899. (508) Schilling and Vorländer, *13*, **308**: 184; 99. (509) Scholze, *Diss.*, Zürich, 1911.

(510) Schreiner, *93*, **122**: 201; 22. (511) Schryver, *4*, **63**: 1327; 93. (512) Schümann, *25*, **33**: 527; 00. (513) Senter, *4*, **107**: 908; 15. (514) Senter and Martin, *4*, **111**: 447; 17. (515) Senter and Tucker, *4*, **109**: 690; 16. (516) Siegfried, *236*, **9**: 334; 10. (517) Siegfried, *202*, **46**: 401; 05. (518) Sirks, *70*, **27**: 207; 08. (519) Skinner, *4*, **73**: 483; 98.

(520) van der Sleen, *70*, **21**: 209; 02. (521) Slothouwer, *70*, **33**: 324; 14. (522) Sluiter, *176*, **9**: 668; 12. (523) Smith, *Diss.*, Lund, 1914. (524) Smith, *7*, **25**: 193; 98. (525) Smith and Jones, *11*, **50**: 1; 13. (525.1) Sonneborn, *Diss.*, Basel, 1902. (525.2) Spiers and Thorpe, *4*, **127**: 538; 25. (526) Springer and Jones, *11*, **48**: 411; 12. (527) Stein, *Diss.*, Bonn, 1906. (528) Steinitz, *Diss.*, Berlin, 1906. (529) Stobbe, *13*, **308**: 114; 99.

(530) Stobbe, *13*, **321**: 105; 02. (531) Stobbe, *52*, **197**: 329; 15. (532) Stobbe and Russwurm, *13*, **308**: 156; 99. (533) Stoddard, *11*, **47**: 1; 12. (534) Stohmann and Kleber, *52*, **45**: 475; 92. (535) Stohmann, Kleber, Langbein and Offenhauer, *52*, **49**: 99; 94. (536) Stohmann and Langbein, *52*, **50**: 388; 94. (537) Stohmann and Schmidt, *52*, **53**: 345; 96. (538) Strecker, *25*, **43**: 1131; 10. (539) Sullivan, *7*, **28**: 523; 99.

(540) Süss, *57*, **26**: 1331; 05. (541) Swarts, *186*, **31**: 675; 96. (542) Swarts, *186*, **35**: 849; 98. (543) Swarts, *186*, **1902**: 731. (544) Swarts, *186*, **1903**: 597. (545) Swarts, *186*, **1904**: 762. (546) Swarts, *27*, **25**: 325; 19. (547) Swarts, *294*, **51**: No. 3; 94. (548) Swarts, *294*, **54**: No. 2; 96. (549) Swarts, *70*, **25**: 244; 06.

(550) Szyszkowski, *7*, **22**: 173; 97. (551) Thiele and Ingle, *13*, **287**: 233; 95. (552) Tiberg, *25*, **49**: 2024; 16. (553) Titherley, *4*, **79**: 391; 01. (554) Traube, *25*, **24**: 1859; 91. (555) Trey, *7*, **46**: 620; 03. (556) Tropsch, *57*, **35**: 775; 14. (557) Trübsbach, *7*, **16**: 708; 95. (558) Verkade, *Diss.*, Delft, 1918. (559) Verkade, *64P*, **19**: 1527; 16.

(560) Verkade, *70*, **35**: 78; 15. (561) Verkade, *70*, **40**: 199; 21. (562) Verkade, *70*, **41**: 208; 22. (563) Vignon, *27*, **1**: 273; 07. (564) Vignon, *34*, **148**: 844; 09. (565) Voerman, *70*, **23**: 265; 04. (566) Voerman, *70*, **26**: 293; 07. (567) Vorländer, *13*, **320**: 66; 02. (568) Vorländer, *25*, **36**: 268; 03. (569) Walden, *25*, **24**: 2025; 91.

(570) Walden, *25*, **29**: 1692; 96. (571) Walden, *25*, **31**: 3167; 98. (572) Walden, *25*, **34**: 4185; 01. (573) Walden, *53*, **23**: 632; 91. (574) Walden, *83*, **6**: 71; 10. (575) Walden, *7*, **2**: 49; 88. (577) Walden, *7*, **8**: 433; 91. (578) Walden, *7*, **10**: 563; 92. (579) Walden, *7*, **10**: 638; 92.

(580) Walden, *7*, **15**: 196; 94. (581) Walden, *7*, **46**: 103; 03. (582) Walker, *4*, **61**: 696; 92. (583) Walker, *4*, **61**: 1088; 92. (584) Walker, *4*, **63**: 495; 93. (585) Walker, *4*, **67**: 347; 95. (587) Walker, *7*, **4**: 319; 89. (588) Walker, *7*, **51**: 706; 05. (589) Walker and Cormack, *4*, **77**: 5; 00.

(591) Walker and Robertson, *68*, **24**: 363; 03. (592) Walker and Walker, *4*, **87**: 961; 05. (593) Walker and Wood, *4*, **77**: 383; 00. (594) Wallach, *13*, **269**: 326; 92. (595) Washburn, *Physical Chemistry*, p. 340, New York, McGraw-Hill Book Co., 1921. (596) Washburn and Strachan, *1*, **35**: 681; 13. (597) Wegscheider, *57*, **16**: 75; 95. (598) Wegscheider, *57*, **23**: 317; 02. (599) Wegscheider, *57*, **26**: 1235; 05.

(600) Wegscheider, *57*, **26**: 1265; 05. (601) Wegscheider, *57*, **37**: 219; 16. (602) Wegscheider and Hecht, *57*, **24**: 413; 03. (603) Wegscheider and Lux, *57*, **30**: 411; 09. (604) Wegscheider and Müller, *57*, **33**: 899; 12. (605) Wegscheider and Rusnov, *57*, **24**: 375; 03. (606) West, *4*, **77**: 705; 00. (607) Whetham, *3*, **44**: 1; 97. (608) White and Jones, *11*, **42**: 520; 09. (609) White and Jones, *11*, **44**: 159; 10.

(610) Wightman and Jones, *11*, **48**: 320; 12. (611) Wightman and Jones, *11*, **46**: 56; 11. (612) Wildermann, *7*, **14**: 247; 94. (613) Wilke, *93*, **119**: 365; 22. (614) Willstätter, *25*, **28**: 3271; 95. (615) Willstätter, *25*, **31**: 1534; 98. (616) Willstätter, *25*, **32**: 1635; 99. (617) Willstätter and Hollander, *13*, **326**: 79; 03. (618) Willstätter and Lessing, *25*, **35**: 2065; 02. (619) Wilsdon and Sidgwick, *4*, **103**: 1959; 13.

(620) Wilsdon and Sidgwick, *4*, **107**: 679; 15. (621) Wilson, *Diss.*, Johns Hopkins, 1899. (622) Winkelblech, *7*, **36**: 546; 01. (623) Wohl and Claussner, *25*, **40**: 2308; 07. (624) Wood, *4*, **89**: 1831; 06. (625) Wood, *7*, **18**: 521; 95. (626) Wright, *Diss.*, Basel, 1902. (627) Zawidzki, *25*, **36**: 1427; 03. (628) Zawidzki, *25*, **36**: 3325; 03. (629) Zecchini, *36*, **23 II**: 601; 93.

(630) Zelinskii, *25*, **29**: 616; 96. (631) Zelinskii, *53*, **23**: 612; 91. (632) Zelinskii and Besredka, *25*, **24**: 459; 91. (633) Zelinskii and Generosow, *25*, **29**: 729; 96. (634) Zelinskii and Isajew, *25*, **29**: 819; 96. (635) Zelinskii and Isgarishev, *53*, **40**: 1379; 08. (636) Zincke, *13*, **296**: 135; 97. (637) Zincke and Greune, *13*, **427**: 221; 22.

ELECTROLYTIC CONDUCTIVITY OF AQUEOUS SOLUTIONS CONTAINING TWO OR MORE SOLUTES

CLARENCE J. WEST

The following bibliography has been compiled chiefly from the data recorded in Annual Tables. The solutes are arranged in the Standard arrangement (*v.* Vol. III, p. viii), except that the organic components are all placed under the inorganic component with which they were studied.

The temperature of the observation and the literature citation follow the second component.

H_2O_2

$LiOH$, 25° (32, 37)
$NaOH$, 25° (32, 74)
KOH, 25° (32, 37)
K_2SO_4 (77)
$RbOH$, 25° (32, 37)
$CsOH$, 25° (32, 37)

HF

H_3BO_3, 25° (1)

HCl

HNO_3, 18° (47.1)
H_3AsO_4, 25° (97, 113)
$BiCl_3$, 25° (85)
H_2BiCl_5, 25° (85)
CH_4O (Methyl alcohol), 25° (53)
$C_2H_4O_2$ (Acetic acid), 18° (3)
C_2H_6O (Ethyl alcohol), 25° (57)
$C_6H_8O_7$ (Citric acid), 18° (93)
$C_6H_{12}N_4$ (Hexamethylenetetramine) (100)
$C_7H_6O_2$ (Benzoic acid), 25° (78)
$C_7H_6O_3$ (Salicylic acid), 25° (78)
H_3BO_3, 25° (78)
$MgCl_2$, 18° (40)
$CaCl_2$, 25° (49)
$LiCl$, 25° (49)
$NaCl$, 18° (82); 25° (30, 49)

Br

KBr, 0° (68)

HBr

SO_2 (6)

I

H_3AsO_4, 25° (113)
KI, 25° (31)

HIO_3

MoO_3, 25° (114)

H_2SO_4

C_2H_6O (Ethyl alcohol), 0, 12° (80)
C_3H_6O (Acetone) (81)
$C_6H_{12}N_4$ (Hexamethylenetetramine) (100)
$ZnSO_4$, 20–40° (109)
$CuSO_4$, 25° (11); 25, 45° (95); 25, 40, 60° (110)
$MgSO_4$, 18° (40)
$KHSO_4$, 25° (8)

NH_3

NH_4Cl, 0, 25° (4)
C_2H_6O (Ethyl alcohol), 18° (55)
$NaOH$, 0, 25° (4)

HNO_3

$Bi(NO_3)_3$, 25° (94)
CH_4N_2O (Urea), 30° (45)
$C_6H_{12}N_4$ (Hexamethylenetetramine) (100)
$C_7H_6O_2$ (Benzoic acid), 25° (78)
$HgNO_3$, 20° (105)
CrO_3, 25° (45)
H_3BO_3, 25° (78)
$Mg(NO_3)_2$, 18° (40)

NH_4OH

NH_4Cl, 25° (57)
CH_4N_2O (Urea), 25° (33)
$C_2H_4O_3$ (Glycolic acid), 25° (36)
$C_3H_6O_3$ (Lactic acid), 25° (36)
$C_4H_8O_3$ (α-Hydroxybutyric acid), 25° (36)
$C_4H_8O_3$ (α-Hydroxyisobutyric acid), 25° (36)
H_2SiO_3, 25° (105.1)
$AgNO_3$, 25° (57)
$Al(OH)_3$, 0, 25° (63)
$CaCl_2$, 25° (57)

NH_4Cl

CH_4O (Methyl alcohol), 0, 25° (4, 5)
CH_4N_2S (Thiourea), 25° (99)
C_2H_6O (Ethyl alcohol), 0, 25° (4, 5); 18° (55)
C_3H_8O (Propyl alcohol), 0, 25° (5)
$NiSO_4$, 25° (56)
$MgCl_2$, 0–35° (115)
$CaCl_2$, 25° (87)
$NaCl$, 25° (88)
KCl, 18° (40); 12, 25° (73); 25° (87)

NH_4Br

CH_4N_2S (Thiourea), 25° (99)
$C_3H_8O_3$ (Glycerol) (67)

NH_4I

$C_3H_8O_3$ (Glycerol), 25–45° (42, 66)

$(NH_4)_2SO_4$

CH_4N_2S (Thiourea), 25° (99)
$MgSO_4$, 18° (40)

NH_4NO_3

CH_4N_2S (Thiourea), 25° (99)
$AgNO_3$ (103)
$Mg(NO_3)_2$, 18° (40)
$NaNO_3$, 25° (88)

H_3PO_4

$C_6H_6O_2$ (Pyrocatechol), 25° (17)
$C_6H_6O_2$ (Resorcinol), 25° (17)
$C_6H_6O_2$ (Hydroquinol), 25° (17)
$C_6H_6O_3$ (Pyrogallol), 25° (17)
$C_6H_8O_7$ (Citric acid) (93)
$FeCl_3$, 18° (43)
MoO_3, 25° (99, 114)
$AlCl_3$, 18° (43)
$BeSO_4$, 18° (43)

H_3AsO_4

$C_6H_8O_7$ (Citric acid), 18° (93)
$FeCl_3$, 18° (43)
MoO_3, 25° (114)
$AlCl_3$, 18° (43)

$Zr(NO_3)_2$

K_2SO_4, 25° (111)

$Pb(IO_3)_2$

$Pb(NO_3)_2$, 25° (60)
KIO_3, 25° (60)
KNO_3, 25° (60)

$TlClO_3$

Tl_2SO_4, 25° (84)

$ZnSO_4$

H_3BO_3, 25° (11)
H_3BO_3 + NaCl, 25° (11)

$CdCl_2$

KCl, 25° (104)

CdI_2

C_3H_6O (Acetone), 0, 25° (70, 71)
KI, 0, 35° (115); 25° (104)

$Cd(CN)_2$

KCN, 18° (96)

$HgCl_2$

NaCl, 25° (104)
KCl, 25° (104)

HgI_2

KI, 18° (96)

$CuCl_2$

NaCl (110)

$CuSO_4$

$CaSO_4$, 25° (59)
$Na_2S_2O_3$, 18, 30, 50° (48)
K_2SO_4, 18° (96)

CuCNS

KCNS, 18° (44)

AgI

KI, 18° (96)

$AgNO_3$

CH_4N_2O (Urea), 25° (57)
CH_4N_2S (Thiourea), 25° (57, 99)
C_2H_6O (Ethyl alcohol), 25° (57)
$C_3H_7NO_2$ (Urethane), 25° (57)
C_5H_5N (Pyridine), 25° (57)
$C_6H_{14}O_6$ (Mannitol), 25° (57)

$FeCl_3$

$AlCl_3$, 25° (73)
K_2SO_4, 25° (111)

$CoCl_2$

CH_4O (Methyl alcohol), 20° (58); 0, 25° (69, 79)
C_2H_6O (Ethyl alcohol), 20° (58); 0, 25° (69, 79)
$C_3H_8O_3$ (Glycerol), 25, 35° (72)
KCN, 25° (101)

$CoBr_2$

$CaBr_2$, 0–35° (115)

$NiCl_2$

$NiSO_4$, 25° (56)
$NiSO_4$ + H_3BO_3, 25° (11, 12, 56)
$NiSO_4$ + H_3BO_3 + NaCl, 25° (11)
KCN, 25° (101)

NiF_2

$NiSO_4$ + H_3BO_3, 25° (12)
$NiSO_4$ + H_3BO_3 + $MgSO_4$, 25° (12)
$NiSO_4$ + H_3BO_3 + Na_2SO_4, 25° (12)

$NiSO_4$

$(NH_4)_2SO_4$, 25° (56)
$MgSO_4$, 25° (56)
NaCl, 25° (56)
NaF, 25° (56)
Na_2SO_4, 25° (56)
K_2SO_4, 25° (56)

$Cr(NO_3)_3$

KCNS, 25° (9)

MoO_3

HCl, 25° (97)
HCl + HIO_3, 25° (97)
HCl + H_3PO_4, 25° (97)
HCl + H_3AsO_3, 25° (97)
HCl + $C_2H_2O_4$ (Oxalic acid), 25° (97)
HCl + $C_2H_4O_2$ (Acetic acid), 25° (97)
HCl + $C_2H_4O_3$ (Glycolic acid), 25° (97)
HCl + $C_3H_6O_2$ (Propionic acid), 25° (97)
HCl + $C_3H_6O_3$ (Lactic acid), 25° (97)
HCl + $C_4H_6O_4$ (Succinic acid), 25° (97)
HCl + $C_4H_6O_5$ (Malic acid), 25° (97)
HCl + $C_4H_6O_6$ (Tartaric acid), 25° (97)
HCl + $C_6H_8O_6$ (Tricarballylic acid), 25° (97)
HCl + $C_6H_8O_7$ (Citric acid), 25° (97)
HCl + $C_7H_{12}O_6$ (Quinic acid), 25° (97)
HCl + $C_8H_8O_2$ (Phenylacetic acid), 25° (97)
HCl + H_3BO_3, 25° (97)
HIO_3, 25° (99)
HNO_3, 25° (97)
$C_2H_2O_4$ (Oxalic acid), 25° (99, 114)
$C_2H_4O_2$ (Acetic acid), 25° (99, 114)
$C_2H_4O_3$ (Glycolic acid), 25° (114)
$C_3H_6O_2$ (Propionic acid), 25° (114)
$C_3H_6O_3$ (Lactic acid), 25° (114)
$C_4H_6O_4$ (Succinic acid), 25° (114)
$C_4H_6O_5$ (Malic acid), 25° (114)
$C_4H_6O_6$ (Tartaric acid), 25° (99, 114)
$C_6H_8O_6$ (Tricarballylic acid), 25° (114)
$C_6H_8O_7$ (Citric acid), 25° (99, 114)
$C_6H_{14}O_6$ (Mannitol), 25° (99)
$C_7H_{12}O_6$ (Quinic acid), 25° (114)
$C_8H_8O_2$ (Phenylacetic acid), 25° (114)
$C_8H_8O_3$ (Mandelic acid), 25° (114)
CrO_3, 25° (97)
H_3BO_3, 25° (99)

WO_3

NaOH, 16° (38)

Various tungstates are also given.

UO_2Cl_2

NaCl, 25° (46)

UO_2SO_4

Na_2SO_4, 25° (46)

(46) also gives the oxalate, acetate, citrate and tartrate with the corresponding Na salts.

H_3BO_3

CH_4N_2O (Urea), 25° (24)
$C_2H_4O_3$ (Glycolic acid), 25° (21)
$C_2H_5NO_2$ (Glycocoll), 25° (24)
$C_2H_5N_3O_2$ (Biuret), 25° (24)
$C_2H_6O_2$ (Glycol), 25° (23)
$C_3H_3N_3O_3$ (Cyanuric acid), 25° (24)
$C_3H_6O_4$ (Glyceric acid), 25° (26)
$C_3H_7ClO_2$ (α-Monochlorohydrin), 25° (14)
$C_3H_8O_2$ (1, 3-Propanediol) (14)
$C_3H_8O_3$ (Glycerol), 25° (14, 23)
$C_4H_4N_2O_4$ (Dialuric acid), 25° (24)
$C_4H_4N_2O_5$ (Alloxan), 25° (24)
$C_4H_4O_6$ (Dihydroxymaleic acid), 25° (26)
$C_4H_6O_2$ (Diacetyl), 25° (20)
$C_4H_6O_5$ (Diglycolic acid), 25° (21)
$C_4H_4O_6$ (*dl*- and *d*-Tartaric acid), 25° (18)
$C_4H_9NO_5$ (Nitrotricarbinylmethane) (14)

$C_4H_{10}O_2$ (1, 4-Butanediol) (14)
$C_4H_{10}O_3$ (Glyceryl α-methyl ether) (65)
$C_5H_6N_4O_5$ (Uric acid glycol), 25° (24)
$C_5H_9NO_4$ (Glutamic acid), 25° (24)
$C_5H_{12}O_4$ (Pentaerythritol), 25° (14, 23)
$C_6H_4N_2O_6$ (3, 5-Dinitropyrocatechol), 25° (15)
$C_6H_5NO_4$ (4-Nitroresorcinol), 25° (15)
C_6H_6O (Phenol), 25° (23)
$C_6H_6O_2$ (Pyrocatechol), 25° (16, 23)
$C_6H_6O_2$ (Resorcinol), 25° (23)
$C_6H_6O_2$ (Hydroquinol), 25° (23)
$C_6H_6O_3$ (Phloroglucinol), 25° (23)
$C_6H_6O_3$ (Pyrogallol), 25° (23)
$C_6H_{10}O_2$ (Divinylglycol), 25° (14)
$C_6H_{10}O_6$ (Gluconic lactone), 25° (26)
$C_6H_{12}O_7$ (Gluconic acid), 25° (26)
$C_6H_{14}O_2$ (Pinacol), 25° (14)
$C_6H_{14}O_6$ (Sorbitol), 25° (14)
$C_6H_{14}O_6$ (Mannitol) (2); 25° (65)
$C_7H_6O_4$ (3, 4-Dihydroxybenzoic acid), 25° (15)
$C_7H_6O_5$ (3, 4, 5-Trihydroxybenzoic acid), 25° (15)
$C_8H_6N_4O_8$ (Alloxantin), 25° (24)
$C_8H_8O_3$ (*dl*- and *d*-Mandelic acid), 25° (18)
$C_8H_{16}O_3$ (α-Hydroxycaprylic acid), 25° (26)
$C_8H_{18}O_6$ (ϵ, ζ-Dimethylmannitol), 25° (65)
$C_9H_{10}O_3$ (β-Phenyl-α-hydroxypropionic acid), 25° (21)
$C_9H_{10}O_3$ (β-Phenyl-β-hydroxypropionic acid), 25° (21)
$C_9H_{10}O_4$ (β-Phenyl-α, β-dihydroxypropionic acid) (19)
$C_9H_{12}O_3$ (Glyceryl α-phenyl ether) (14)
$C_9H_{18}O_6$ (Mannitol monoacetone) (65)
$C_{10}H_8O_2$ (1, 2-Dihydroxynaphthalene), 25° (15, 16)
$C_{10}H_8O_2$ (2, 3-Dihydroxynaphthalene), 25° (16)
$C_{10}H_{22}O_6$ (β, γ, ϵ, ζ-Tetramethylmannitol), 25° (65)
$C_{10}H_{22}O_6$ (γ, δ, ϵ, ζ-Tetramethylmannitol), 25° (65)
$C_{11}H_{24}O_6$ (Pentamethylmannitol), 25° (65)
$C_{12}H_{22}O_6$ (Mannitol diacetone), 25° (65)
$HBF_4 + Pb(BF_4)_2$, 25° (13)
KF, 25° (1)

$Al(OH)_3$

$Mg(OH)_2$, 25° (62)
$Ca(OH)_2$, 25° (62)
$Sr(OH)_2$, 25° (62)
$Ba(OH)_2$, 25° (62)
NaOH, 0, 25° (63)
K_2SO_4, 0–35° (115)

$Th(SO_4)_2$

K_2SO_4, 20° (7)

$La(IO_3)_3$

$La(NO_3)_3$, 25° (60)
$NaNO_3$, 25° (60)
KIO_3, 25° (60)

BeO

$C_3H_6O_3$ (Lactic acid), 25° (34)

$Be(OH)_2$

$C_2H_4O_3$ (Glycolic acid), 25° (35)
$C_4H_8O_3$ (Hydroxyisobutyric acid), 25° (35)

$MgCl_2$

$CaCl_2$, 25° (49, 73, 87)
$BaCl_2$, 18° (47)
$Ba(NO_3)_2$, 18° (47)
NaCl, 18° (47); 25° (49, 88)
KCl, 18° (40, 47); 25° (87)

$Mg(ClO_3)_2$

$NaClO_3$, 18° (40)

$MgBr_2$

KBr, 18° (40); 0–35° (115)

$MgSO_4$

$CaSO_4$, 25° (59)
Na_2SO_4, 18° (40)
K_2SO_4, 18° (40)

$Mg(NO_3)_2$

$Ca(NO_3)_2$, 25° (73, 88)
$Sr(NO_3)_2$, 25° (73)
$NaNO_3$, 25° (88)
KNO_3, 18° (40)

$Ca(OH)_2$

CH_2N_2 (Cyanamide), 25° (76)
$C_6H_{12}O_6$ (Dextrose), 25° (92)
$C_6H_{12}O_6$ (Levulose), 25° (92)

$CaCl_2$

CH_4O (Methyl alcohol), 25° (57)
C_2H_6O (Ethyl alcohol), 25° (57)
$Ca(NO_3)_2$, 25° (73)
$SrCl_2$, 25° (73)
$BaCl_2$, 18° (47)
$Ba(NO_3)_2$, 18° (47)
$SrCl_2$, 25° (87)
NaCl (47); 25° (87, 88)
KCl, 25° (73, 87)

$CaSO_4$

KNO_3, 25° (59)

$Ca(NO_3)_2$

$Sr(NO_3)_2$, 25° (88)
NaCl, 25° (88)
$NaNO_3$, 25° (88)
KCl, 25° (88)

$Ba(OH)_2$

$C_6H_{12}O_6$ (Dextrose), 25° (92)
$C_6H_{12}O_6$ (Levulose), 25° (92)

$BaCl_2$

$Ba(NO_3)_2$, 18° (47)
$SrCl_2$, 25° (104)
NaCl, 18° (47)
$NaNO_3$, 18° (47)

$SrCl_2$

$C_3H_8O_3$ (Glycerol) (67)
NaCl, 25° (88)
KCl, 25° (87)

$Sr(NO_3)_2$

$NaNO_3$, 25° (88)
KNO_3, 25° (88)

LiCl

CH_4O (Methyl alcohol), 0, 26° (4)
CH_4N_2O (Urea), 20° (86)
C_2H_6O (Ethyl alcohol), 0, 26° (4)
$C_2H_6O_2$ (Glycol), 0, 26° (4)
C_3H_8O (Propyl alcohol), 0, 26° (4)
$C_3H_8O_3$ (Glycerol), 20° (86); 0, 26° (4)
$C_{12}H_{22}O_{11}$ (Sucrose), 20° (86)
KCl, 25° (49)

LiBr

$C_3H_8O_3$ (Glycerol), 25, 35° (72)
NaBr, 25° (73)

$LiNO_3$

CH_4O (Methyl alcohol) + C_3H_6O (Acetone), 0, 25° (71)
C_3H_6O (Acetone), 0, 25° (71); 0° (70)
C_5H_5N (Pyridine), 25° (61)

NaOH

CH_2N_2 (Cyanamide), 25° [76]
C_2H_6O (Ethyl alcohol), 0, 25° [4]; 25° [57]
C_3H_8O (Propyl alcohol), 0, 25° [4]
$C_4H_{12}INO$ (Trimethylmethoxyammonium iodide), 25° [108]
$C_5H_{14}INO$ (Trimethylethoxyammonium iodide), 25° [108]
$C_6H_{12}O_6$ (Dextrose), 25° [92]
$C_6H_{12}O_6$ (Levulose), 25° [92]
$C_2H_3O_2Na$ (Na acetate), 2, 4° [75]
$Na_2B_4O_7$ (Borax), 0, 18° [91]

NaCl

CH_4O (Methyl alcohol), 0, 25° [5]
CH_4N_2O (Urea), 25° [57]
C_2H_6O (Ethyl alcohol), 0, 25° [5]
C_3H_8O (Propyl alcohol), 0, 25° [5]
C_3H_8O (Isopropyl alcohol), 0, 25° [5]
$C_3H_8O_3$ (Glycerol), 25° [90]
$C_4H_6O_6$ (Tartaric acid), 25° [102]
$C_6H_{12}O_6$ (Glucose), 25° [4, 51]
$C_6H_{14}O_6$ (Mannitol), 25° [90]
$C_7H_5NO_3S$ (Saccharin), 18° [10]
$C_7H_{14}O_6$ (α-Methylglucoside), 25° [4, 51]
$C_7H_{14}O_6$ (β-Methylglucoside), 25° [51]
$C_{12}H_{22}O_{11}$ (Sucrose), 25° [4, 51]
$C_{12}H_{22}O_{11}$ (Lactose), 25° [51]
$C_{12}H_{22}O_{11}$ (Melibiose), 25° [4, 51]
$C_{18}H_{32}O_{16}$ (Raffinose), 25° [4, 51]
Congo red, 18° [27]
Na_2SO_4, 25° [104]
$NaNO_3$, 18° [47]
KCl, 18° [47]; 25° [87, 104, 107]
K_2SO_4, 18° [47]
KNO_3, 18° [47]; 25° [88]

NaBr

KBr, 25° [107]

NaI

KI, 18° [47]; 25° [107]

Na_2SO_4

K_2SO_4, 18° [47]
KNO_3, 18° [47]

$NaNO_3$

$C_3H_8O_3$ (Glycerol) [67]
$C_6H_{12}O_6$ (Dextrose), 25° [51]
$C_7H_{14}O_6$ (α-Methylglucoside), 25° [51]
$C_{12}H_{22}O_{11}$ (Sucrose), 25° [51]
KCl, 25° [88]
KNO_3, 18° [47]; 25° [88]

Na_2CO_3

K_2SO_4, 18° [47]
K_2CO_3, 18° [47]

Conductivities of the Na derivatives of acetophenone, acetoxime, benzoin, benzophenone, chloral hydrate, phenol and succinimide in ethyl alcohol and water at 18° are given in [55].

KOH

C_2H_6O (Ethyl alcohol), 18° [55]
$C_6H_{12}O_6$ (Dextrose), 25° [92]
$C_6H_{12}O_6$ (Levulose), 25° [92]
$C_{16}H_{31}O_2K$ (K palmitate), 20, 90° [54]

KCl

CH_4N_2O (Urea), 20° [86]; 25° [57]
CH_4N_2S (Thiourea), 25° [57, 99]
CH_4O (Methyl alcohol), 0, 25° [4, 5]
C_2H_4O (Acetaldehyde), 0, 25° [4]
C_2H_6O (Ethyl alcohol), 0, 25° [4, 5]; 25° [57]
$C_2H_6O_2$ (Glycol), 0, 25° [4]
C_3H_6O (Acetone), 0, 25° [4]; 25° [57]
$C_3H_7NO_2$ (Urethane), 25° [57]
C_3H_8O (Propyl alcohol), 0, 25° [4, 5]
$C_3H_8O_3$ (Glycerol), 0, 25° [4]; 25, 35, 45° [67]; 20° [86]
$C_4H_6O_4$ (Succinic acid), 25° [102]
$C_4H_{10}O$ (Isobutyl alcohol), 0, 25° [4]
$C_4H_{10}O$ (Ethyl ether), 0° [4]; 25° [57]
C_5H_5N (Pyridine), 25° [57]
$C_6H_{12}O_3$ (Paraldehyde), 0° [4]
$C_6H_{12}O_6$ (Dextrose), 25° [4, 51]
$C_6H_{14}O_6$ (Mannitol), 25° [57]; 20° [86]
$C_7H_{14}O_6$ (α-Methylglucoside), 25° [4, 51]
$C_7H_{14}O_6$ (β-Methylglucoside), 25° [51]
$C_{12}H_{22}O_{11}$ (Lactose), 25° [51]
$C_{12}H_{22}O_{11}$ (Melibiose), 25° [4, 51]
$C_{12}H_{22}O_{11}$ (Sucrose), 25° [4, 51], 20° [86]
$C_{18}H_{32}O_{16}$ (Raffinose), 20° [86]; 25° [4, 51]
$C_{36}H_{62}O_{31}$ (Inulin), 20° [86]
$KClO_4$, 25° [84]
K_2SO_4, 25° [84]
KNO_3, 18° [3]; 25° [88]

KBr

CH_4O (Methyl alcohol), 0, 25° [4]
C_2H_6O (Ethyl alcohol), 0, 25° [4]
$C_2H_6O_2$ (Glycol), 0, 25° [4]
C_3H_8O (Propyl alcohol), 0, 25° [4]
$C_3H_8O_3$ (Glycerol), 0, 25° [4]

KI

CH_4O (Methyl alcohol), 0, 25° [4, 69, 79]
C_2H_6O (Ethyl alcohol), 0, 25° [4, 69, 79]
$C_2H_6O_2$ (Glycol), 0, 25° [4]
$C_3H_8O_3$ (Glycerol) [72]
$C_8H_{20}NI$ (Tetraethylammonium iodide), 25° [89]

K_2SO_4

$C_4H_4O_6K_2$ (K tartrate) [28]

RbCl

C_3H_6O (Acetone), 15–45° [41]

RbBr

C_3H_6O (Acetone), 15–45° [41]
$C_3H_8O_3$ (Glycerol), 25–45° [42, 66]

RbI

C_3H_6O (Acetone), 15–45° [41]

$RbNO_3$

C_3H_6O (Acetone), 15–45° [41]

LITERATURE

(For a key to the periodicals see end of volume)

[1] Abegg, Fox and Herz, *93*, **35**: 129; 03. [2] Ageno and Valla, *36*, **43 II**: 163; 13. [3] Andrejev and Saposhnikov, *53*, **44**: 901; 11. [4] Armstrong and Crothers, *135*, **103**: 121; 11. [5] Armstrong and Eyre, *5*, **84**: 123; 10. [6] Bagster and Steele, *33*, **8**: 51; 12. [7] Barre, *34*, **151**: 231; 10. [8] Bergius, *7*, **72**: 338; 11. [9] Bjerrum, *137*, **7**, No. 12.
[10] de Blasi, *178*, **7**: 503; 10. [11] Blum, *78*, **36**: 213; 19. [12] Blum, *33*, **24**: 1109; 21. [13] Blum, Liscomb, Jencks and Bailey, *78*, **36**: 243; 19. [14] Böeseken, *70*, **34**: 96; 15. [15] Böeseken, *70*, **34**: 272; 15. [16] Böeseken, Anema and Brevet, *70*, **41**: 178; 22. [17] Böeseken and Brackmann, *70*, **34**: 279; 15. [18] Böeseken and van der Ent, *70*, **37**: 179; 17. [19] Böeseken and de Graaff, *70*, **41**: 199; 22.
[20] Böeseken and van der Hoek Ostende, *70*, **37**: 162; 17. [21] Böeseken and Kalshoven, *70*, **37**: 130; 17. [22] Böeseken and Kerstjens, *64P*, **18**: 719; 16. [23] Böeseken and van Rossem, *70*, **30**: 392; 11. [24] Böeseken, Sturm and Goettsch, *70*, **37**: 144; 17. [25] Böeseken and de Voogd, *70*, **42**: 745; 23. [26] Böeseken, Weisfelt, van der Spek, van Loon and Goettsch, *70*, **37**: 165; 17. [27] Bogoiavlenski, *53*, **44**: 1813; 12. [28] Bongiovanni, *36*, **42 I**: 179; 12. [29] Braune, *7*, **85**: 170; 13.
[30] Bray and Hunt, *1*, **33**: 781; 11. [31] Bray and MacKay, *1*, **32**: 914; 10. [32] Bredig and Calvert, *9*, **7**: 622; 01. [33] Burke, *1*, **42**: 2500; 20. [34] Calcagni, *22*, **19 II**: 290; 10. [35] Calcagni, *22*, **21 II**: 343; 12. [36] Calcagni and Bernardini, *22*, **20 II**: 261; 11. [37] Calvert, *7*, **38**: 513; 01. [38] Copaux, *93*, **74**: 351; 11. [39] Copaux, *6*, **26**: 22; 12.

(40) Costachescu and Apostoi, *177*, **7**: 101; 11. (41) Davis, Hughes and Jones, *7*, **85**: 513; 13. (42) Davis and Jones, *7*, **81**: 68; 13. (43) Dede, *93*, **125**: 28; 22. (44) Dhar, *93*, **85**: 44; 14. (45) Dhar, *93*, **85**: 198; 14. (46) Dittrich, *7*, **29**: 449; 99. (47) Doroschewskii and Dworzaneyk, *53*, **46**: 371, 455, 1686; 13. (47.1) Doroschewskii and Fridmann, *53*, **47**: 617; 15. (48) Dutoit, *42*, **11**: 650; 13. (49) Engér, *147*, **6**: No. 5; 25.

(50) Euler and Blomdahl, *19*, **4**: 1; 13. (51) Glover, *4*, **99**: 379; 11. (52) Goldschmidt, *7*, **70**: 627; 10. (53) Goldschmidt and Thuesen, *7*, **81**: 30; 13. (54) Goldschmidt and Weissmann, *9*, **18**: 380; 12. (55) Hägglund, *42*, **10**: 207; 11. (56) Hammond, *78*, **45**: 219; 24. (57) Hantzsch, *93*, **25**: 332; 00. (58) Hardt, *Diss.*, Braunschweig, 1901. (59) Harkins and Paine, *1*, **41**: 1155; 19.

(60) Harkins and Pearce, *1*, **38**: 2679; 16. (61) Hartley, Thomas and Applebey, *4*, **93**: 538; 08. (62) Heyrovsky, *135*, **125**: 198; 22. (63) Heyrovsky, *4*, **117**: 1013; 20. (64) Hūmi, *Diss.*, Zürich, 1910. *10*, **1**: 487; 10. (65) Irvine and Steele, *4*, **107**: 1221; 15. (66) Jones and Davis, *152*, **No. 180**: 179; 13. (67) Jones and Guy, *152*, **No. 180**: 153; 13. (68) Jones and Hartmann, *78*, **30**: 295; 16. (69) Jones and Kreider, *152*, **No. 180**: 89; 13.

(70) Jones and Mahin, *7*, **69**: 389; 09. (71) Jones and Mahin, *152*, **No. 180**: 111; 13. (72) Jones and Schmidt, *152*, **No. 180**: 133; 13. (73) Jones and Stine, *152*, **No. 180**: 11; 13. (74) Joyner, *93*, **77**: 103; 11. (75) Kaiser, *Diss.*, Utrecht, 1914. *10*, **4**: 977; 14. (76) Kameyamu, *78*, **40**: 131; 21. (77) Kasanecki, *53*, **46**: 1125; 14. (78) Kendall and Andrews, *1*, **43**: 1545; 21. (79) Kreider and Jones, *11*, **45**: 282; 11.

(80) Kremann and Brassert, *57*, **31**: 195; 10. (81) Kremann and Hönel, *57*, **34**: 1469; 13. (82) Miles, *68*, **35**: 188; 15. (83) Millar, *7*, **85**: 129; 13. (84) Noyes, Boggs, Farrell and Stewart, *1*, **33**: 1650; 11. (85) Noyes, Hall and Beattie, *1*, **39**: 2526; 17. (86) Öholm, *60*, **55**: No. 5; 13. (87) Ordeman, *152*, **No. 260**; 18. (89) Philip and Courtman, *4*, **97**: 1261; 10.

(90) Pissarjewsky and Lemcke, *7*, **52**: 479; 05. (91) Polack, *83*, **10**: 177; 15. (92) Powell, *4*, **107**: 1335; 15. (93) Pratolongo, *22*, **22 I**: 87; 13. (94) Quartaroli, *36*, **43 I**: 97; 13. (95) Richardson and Taylor, *78*, **20**: 179; 11. (98) Rieger, *9*, **7**: 863, 871; 01. (97) Rimbach and Neizert, *93*, **52**: 397; 07. (98) Rosenheim and Bertheim, *93*, **34**: 427; 03. (99) Rosenheim and Loewenstamm, *93*, **34**: 62; 03.

(100) Russo, *36*, **44 I**: 17; 14. (101) Russo, *36*, **45 I**: 6; 15. (102) Sachanov, *53*, **46**: 88; 14. (103) Sachanov and Goncarov, *53*, **47**: 1252; 14. (104) Sandonnini, *36*, **46 II**: 205; 16. (105) Schilow, *93*, **133**: 55; 24. (105.1) Schwarz, *25*, **49**: 2538; 16. (106) Sluiter, *176*, **9**: 668; 11. (107) Stearn, *1*, **44**: 670; 22. (108) Stewart and Maeser, *1*, **46**: 2583; 24. (109) Tartar and Keyes, *45*, **13**: 1127; 21.

(110) Thompson and Hamilton, *78*, **17**: 291; 10. (111) Wagner, *57*, **34**: 931; 13. (112) Walker and Hambly, *4*, **71**: 61; 97. (113) Washburn and Strachan, *1*, **35**: 681; 13. (114) Wintgen, *93*, **74**: 281; 12. (115) Woitaschowski, *53*, **45**: 429; 13.

TRANSFERENCE NUMBERS OF ELECTROLYTES IN AQUEOUS SOLUTION

K. G. Falk

In the following tables the values given are in all cases the transference numbers of the cation multiplied by 10^3, and except as otherwise noted are with respect to water as the reference substance. Concentrations, C, are in equivalents per liter except those marked "Wt. N" which are in equivalents per kg H_2O. For theoretical discussion of the numbers and methods of weighting results obtained by the gravimetric method, *see* Noyes and Falk, *1*, **33**: 1436; 11.

Les valeurs données dans les tables suivantes sont dans tous les cas, les nombres de transport des cations multipliés par 10^3 et, à moins d'une autre indication, se rapportent à l'eau comme substance de référence. Les concentrations, C, sont exprimées en équivalents par litre, à l'exception de celles marquées "Wt. N" qui sont exprimées en équivalents par kg H_2O. Pour la discussion théorique des nombres et des méthodes d'appréciation des résultats par la méthode gravimétrique, *voir* Noyes and Falk, *1*, **33**: 1436; 11.

In den folgenden Tabellen stellen alle angegebenen Werte die Überführungszahlen des Kations multipliziert mit 10^3 dar. Sie gelten, stets, wenn nicht etwas anderes bemerkt, in Bezug auf Wasser. Die Konzentrationen, C, sind in Äquivalenten pro Liter angegeben, mit Ausnahme der Stellen, wo die Bezeichnung "Wt. N" steht, welche Äquivalente pro kg Wasser bedeutet. Die theoretischen Besprechungen der Zahlen und der Methoden zur Abschätzung der Ergebnisse nach der gravimetrischen Methode, findet man in der Abhandlung von Noyes and Falk, *1*, **33**: 1436; 11.

I valori riportati nelle tabelle seguenti rappresentano sempre il numero di trasporto del catione moltiplicato per 10^3, e, salvo indicazioni contrarie, si riferiscono all'acqua. Le concentrazioni, C, sono in equivalenti per litro, eccettuati i casi contrassegnati con "Wt. N" nei quali le concentrazioni sono espresse in equivalenti per kg di acqua. Per la discussione teorica dei numeri e circa l'apprezzamento dei risultati ottenuti col metodo gravimetrico, *vedi* Noyes and Falk, *1*, **33**: 1436; 11.

Table 1.—Gravimetric Method

Electrolyte	t, °C	$10^3 n_k$	$C \times 10^3$	Lit.
Uni-univalent electrolytes				
HF	*v.* Table 2 (7)			
HCl	*v.* Table 2 (**2, 14, 22, 24, 43, 44, 45, 47, 48, 56**)			
HI	25	825	60– 80	(55)
		828	80– 150	
		825	150– 250	
HNO_3	*v.* Table 2 (**2, 24, 44**)			
NH_4Cl	*v.* Table 2 (**2, 24**)			
TlCl	22	484	8– 15	(2)
$AgClO_3$	25	499	15– 25	(30)
$AgClO_4$	25	486	15– 25	(30)
$AgNO_2$	25	481	2– 8	(13)
		461	8– 15	
$AgNO_3$	*v.* Table 2 (**2, 24, 25, 26, 29, 30, 41**)			
$AgC_2H_3O_2$	0, 24, 28, 46, 96°C, *v.* (**2, 30, 41**)			
LiCl	18	*v.* Table 2		(24, 47)
	25	324	40– 60	(2)
		276	1.25 Wt. N	(59)
	97	390	40– 60	(2)
NaOH	25	201	25– 40	(2)
NaCl	*v.* Table 2 (**2, 22, 24, 59, 60**)			
NaBr	*v.* Table 2 (**2, 24**)			
$NaNO_3$	19	371	40– 60	(2)
KCl	*v.* Table 2 (**2, 24, 47, 53, 56, 59**)			
KBr	*v.* Table 2 (**24**)			
KI	25	495	40– 60	(2)
$KMnO_4$	23	441	40– 60	(2)
RbCl	22	485	40– 60	(2)
CsCl	20	492	40– 60	(2)
	25	485	1.1 Wt. N	(60)
Uni-bivalent electrolytes				
H_2SO_4	*v. also* Table 2 (**2, 24, 57, 61**)			
	96	696	40– 60	(2)
Tl_2SO_4	*v.* Table 2 (**2, 15**)			
$Ag_2S_2O_6$	0–30	396	15– 25	(30)
Ag_2SiF_6	22	525	25– 40	(30)
Na_2SO_4	*v.* Table 2 (**24**)			
K_2SO_4	*v.* Table 2 (**24, 42**)			
$Pb(NO_3)_2$	*v.* Table 2 (**15**)			

TABLE 1.—(*Continued*)

Electrolyte	t, °C	$10^3 n_k$	$C \times 10^3$	Lit.
$CdCl_2$	*v. also* Table 2 (24)			
	8	433	250– 400	(2)
	25	431	40– 60	(2)
	96	525	40– 60	(2)
$CdBr_2$	*v.* Table 2 (24)			
CdI_2	*v.* Table 2 (24)			
$CuCl_2$	23	405	40– 60	(2)
$CuBr_2$	25	445	150– 250	(8)
$MnCl_2$	18	387	40– 60	(2)
$CoCl_2$	18	404	40– 60	(2)
$CoBr_2$	25	409	150– 250	(8)
$MgCl_2$	21	385	40– 60	(2)
$Ca(OH)_2$	25	214	25– 40	(2)
$CaCl_2$	*v. also* Table 2 (2, 53)			
	49	445	8– 15	(2)
	96	470	8– 15	(2)
		426	80– 150	(2)
		451	150– 250	(2)
$Ca(NO_3)_2$	18	450	2– 8	(53)
$SrCl_2$	20	433	250– 400	(2)
$BaCl_2$	*v.* Table 2 (2, 22, 24, 42)			
$Ba(NO_3)_2$	*v.* Table 2 (42)			
Cu $(C_7H_5O_3)_2$, Salicylate	25	626	10– 30	(20)
$AgC_{10}H_7SO_3$	25–30	612	8– 25	(30)
$AgC_9H_{11}SO_3$, Pseudo-cumenesulfonate	0	727	15– 25	(30)
	24	707	15– 25	(30)
	29	705	15– 25	(30)
$AgC_2H_5SO_4$	25	616	2– 8	(30)
		613	15– 25	(30)
$AgC_6H_5SO_3$	25	653	15– 25	(30)
Cobaltammine complex salts	15–20		8– 40	(31)
$(Na_2O)_x(SiO_2)_y$				(21)
Bi-bivalent electrolytes				
$CdSO_4$	*v.* Table 2 (24)			
$CuSO_4$	*v. also* Table 2 (24)			
	0	385	8– 15	(2)
		389	80– 150	
	11	316	600– 800	(22)
		304	800–1000	(2)
	50	393	80– 150	
$MgSO_4$	*v.* Table 2 (2, 22, 24)			
$CaSO_4$	18	441	2– 8	(53)

TABLE 2.—GRAVIMETRIC METHOD, BEST VALUES
For literature, *v.* Table 1

Electrolyte	t, °C	$C \times 10^3$								
		5	10	20	50	100	200	300	500	1000
HF	25			860	845	821	787	763	732	694
HCl	0	847	846	844	839	834				
	10	840	840	841						
	18	832	833	833	834	835	837	838	840	844
	30		822	822	822					
	50		801							
	76					781				
	96		748							
HNO_3	20	839	840	841	844					
NH_4Cl	0		489	489						
	18		492	492	492					
	30		495	495						
$AgNO_3$	0			461						
	18		471	471	471	471				
	25		477	477	477					
	30	481	481	481	481	481	481	481	481	

TABLE 2.—(*Continued*)

Electrolyte	t, °C	$C \times 10^3$								
		5	10	20	50	100	200	300	500	1000
LiCl	18		332	328	320	313	304	299		
NaCl	0	387	387	387	386	385				
	18	397	397	396	393	390	385	380	374	365
	30	404	404	404	404	403				
	96				442	442	442			
NaBr	18	395	395	395						
KCl	0	493	493	493	493	492	491			
	10		495	495	495	495				
	18	496	496	496	496	495	494	493	492	490
	30	498	498	498	498	497	496			
KBr	18		495	495						
H_2SO_4	8			835	835	835				
	20			822	822	822	820	818	816	812
	32			808	808	808				
$Pb(NO_3)_2$	25				487	487				
Tl_2SO_4	25				478	476				
$CdCl_2$	18	430	430	430	430	430				
$CdBr_2$	18	430	430	430	430	429	410	389	350	222
CdI_2	18	445	444	442	396	296	127	46	3	
$CaCl_2$	20	440	432	424	413	404	395	389		
	25				418	409				
$BaCl_2$	0	439	437	432						
	16					420	408	401	391	
	25				438	427	415			
	30	445	444	443						
	50		475							
$Ba(NO_3)_2$	25				456	456	456			
Na_2SO_4	18		392	390	383					
K_2SO_4	18		494	492	490					
	25				496	494	493			
$CdSO_4$	18		389	384	374	364	350	340	323	294
$CuSO_4$	18			375	375	373	361	348	327	
$MgSO_4$	18	388	385	381	373					
	30		388	386	380					

TABLE 3.—MOVING BOUNDARY METHOD (9, 10, 11, 12, 33, 34, 34.5, 35, 36, 37, 39, 50, 51, 52)

$C \times 10^3$ / Electrolyte	20	50	100	50	100	200
	Values of $10^3 n_k$, 18°C			Values of $10^3 n_k$, 25°C		
HCl	835		835	828	832	
HNO_3*	846		855	840	844	849
NH_4NO_3					513	
NH_4Cl	492		489		490	
NH_4Br	483		481			
NH_4I	489		484			
$AgNO_3$				466	469	
NaOH			158			
NaCl		387	383		386	
NaBr		381	376			
NaI		381	376			
$NaNO_3$					410	
KOH			257			
KCl	493		492		492	490
$KClO_3$	534		536		537	
$KClO_4$			523			
KBr	482		481		480	
					485	
$KBrO_3$	567		570		570	
KI	487		486		483	

TABLE 3.—(*Continued*)

Electrolyte \ $C \times 10^3$	20	50	100	50	100	200
	Values of $10^3 n_k$, 18°C			Values of $10^3 n_k$, 25°C		
KNO_3	502		502		501 512	
RbCl	497		494			
RbBr	495		492			
RbI	498		497			
CsCl	504		500			
CsBr	497		493			
CsI	497		497			
H_2SO_4	833		828			
$MgCl_2$		368	352			
$MgBr_2$	385	368	350			
MgI_2	388		350			
$CaCl_2$	413		398		396	
$CaBr_2$	409		396			
CaI_2	416		400			
$SrCl_2$	412		400		404	
$SrBr_2$	410		392			
SrI_2	416		393			
$BaCl_2$	435		419		416	
$BaBr_2$	422		408			
BaI_2	426		415			
K_2SO_4	488		485		479	

* 25°, $10^3 C = 10$ or 20, $10^3 n_k = 838$.

TABLE 4.—ELECTROMOTIVE FORCE METHOD

Electrolyte	t, °C	$C \times 10^3$ 5	10	20	30	50	100	200	300	500	1000	Lit.
HCl	18	832	832	832	832	832	832	832				(16, 38)
	25				830							(19)
LiCl	25	341	334	327	323	318	311	304	299	293	286	(34)
NaOH	25		203	197	194	189	183	177	174	169	163	(18)
KOH	25				263	263	263	263	263	263	263	(27, 28)
KCl	25	496	496	496	496	496	496	496	496	496	496	(1, 6, 38)
KBr	25	496	496	496	496	496	496	495	491	488	485	(46)
	30	496	496	496	496	496	496	495	492	489	486	(46)
	35	496	496	496	496	496	496	495	493	491	489	(46)
H_2SO_4	25						813					(17)
$CuCl_2$	25		420	416	411	404	387	355	322	289	259	(32)
$SrCl_2$	25		424	417	412	405	393	376	360	343	306	(32)
$BaCl_2$	25		439	431	425	418	406	390	383	377	372	(32)

TABLE 5.—TRUE TRANSFERENCE NUMBERS AND RELATIVE HYDRATION VALUES

For critical review of the literature and some additional data, *see* (46.5)

Electrolyte	C, Wt. N	t, °C	Reference substance	$10^3 n_k$	Lit.
HCl	1.0–3.1	Room	Mannitol Resorcinol	844	(5)
HCl	1.0	18	Allyl alcohol	844	(56)
HCl	2.5	18		825	
KCl	0.5	18		502	
KCl	1.0	18		502	
KCl	1.4	18		498	
KCl	1.9	18		496	
KCl	2.5	18		492	
KCl	1.24	25		495	
LiCl	1.28	25		304	(59)
NaCl	1.21	25	Raffinose	383	
NaCl	1.12	25		377	(60)
CsCl	1.1	25		491	

Relative Hydration Values of the Ions

Average number of water molecules carried by the indicated ion combined as chloride as it moves through the solution.

HCl: $N_w^{H+} = 0.28 \pm 0.04 + 0.185 N_w^{Cl-}$.
CsCl: $N_w^{Cs+} = 0.67 \pm 0.01 + 1.03 N_w^{Cl-}$.
KCl: $N_w^{K+} = 1.3 \pm 0.2 + 1.02 N_w^{Cl-}$.
NaCl: $N_w^{Na+} = 2.0 \pm 0.2 + 1.61 N_w^{Cl-}$.
LiCl: $N_w^{Li+} = 4.7 \pm 0.4 + 2.29 N_w^{Cl-}$.

TABLE 6.—MIXTURES OF ELECTROLYTES

Electrolytes	C	Tr. No. $\times 10^3$	Lit.
KCl K_2SO_4	0.2 0.2	Cl^- 289	(40)
$FeCl_3$ HCl	0.14 0.06–0.19	Fe‴ 384	(23)
$FeCl_3$ HCl	0.44 0.06–0.31	Fe‴ 359	
$FeCl_3$ HCl	1.16–1.32 0.50–0.60	Fe‴ 297	
$FeCl_3$ HCl	0.16 0.23	Fe‴ 301	
$FeCl_3$ HCl	0.16 0.22	Fe‴ 313	
$FeCl_2$ HCl	0.17 0.13	Fe″ 375	(54)
$FeCl_2$ HCl	0.49 0.12–0.18	Fe″ 326	
$FeCl_2$ HCl	1.0 0.04–0.19	Fe″ 300	

Electrolytes, KCl, NaCl

Total salt concentration $0.2N$; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.	Total salt concentration $0.2N$; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.
4:1	K^+ 369 Na^+ 63	(4)	1:2	K^+ 159 Na^+ 246	(4)
3:1	K^+ 372 Na^+ 84		1:3	K^+ 129 Na^+ 239	
2:1	K^+ 337 Na^+ 109		1:4	K^+ 108 Na^+ 288	
1:1	K^+ 260 Na^+ 163				

LITERATURE

(For a key to the periodicals see end of volume)

(1) Beattie, *1*, **42**: 1128; 20. (2) Bein, *7*, **27**: 1; 98. (3) Braley and Hall, *1*, **42**: 1770; 20. (4) Braley and Rippie, *1*, **49**: 1493; 27. (5) Buchböck, *7*, **55**: 563; 06. (6) Corran and Lewis, *1*, **44**: 1673; 22. (7) Davies and Hudleston, *4*, **125**: 260; 24. (8) Denham, *7*, **65**: 641; 09. (9) Denison, *7*, **44**: 575; 03.

(10) Denison, *83*, **5**: 165; 09. (11) Denison and Steele, *7*, **57**: 110; 06. (12) Denison and Steele, *62*, **205**: 449; 06. (13) Dhar and Bhattacharyya, *93*, **83**: 141; 13. (14) Drucker and Krensjavi, *7*, **62**: 731; 08. (15) Falk, *1*, **32**: 1555; 10. (16) Ferguson, *50*, **20**: 326; 16. (17) Ferguson and France, *1*, **43**: 2150; 21. (18) Ferguson and Schluchter, *78*, **51**: preprint; 27. (19) France and Moran, *1*, **46**: 19; 24.

(20) Hamer and Bury, *4*, **1927**: 333. (21) Harman, *50*, **30**: 359; 26. (22) Hopfgartner, *7*, **25**: 115; 98. (23) Hopfgartner, *57*, **36**: 751; 15. (24) Jahn, *7*, **37**: 673; 01. **58**: 641; 07. (25) Jones and Bassett, *11*, **32**: 409; 04. (26) Jones and Rouiller, *11*, **36**: 427; 06. (27) Knobel, *1*, **45**: 70; 23. (28) Knobel, Worcester and Briggs, *1*, **45**: 77; 23. (29) Krumreich, *9*, **22**: 446; 16.

(30) Loeb and Nernst, *7*, **2**: 948; 88. (31) Lorenz and Posen, *93*, **96**: 81; 16. (32) Lucasse, *1*, **47**: 743; 25. (33) MacInnes, Rockefeller Institute for Medical Research, New York City, *0*. (34) MacInnes and Beattie, *1*,

42: 1117; 20. (34,5) MacInnes and Brighton, *1*, **47**: 994; 25. (35) MacInnes and Cowperthwaite, *83*, **23**: 400; 27. (36) MacInnes, Cowperthwaite and Blanchard, *1*, **48**: 1909; 26. (37) MacInnes, Cowperthwaite and Huang, *1*, **49**: 1710; 27. (38) MacInnes and Parker, *1*, **37**: 1445; 15. (39) MacInnes and Smith, *1*, **45**: 2246; 23.
(40) Mackay, *1*, **33**: 308; 11. (41) Mather, *11*, **26**: 473; 01. (42) Noyes, *1*, **23**: 37; 01. (43) Noyes, *1*, **25**: 165; 03. (44) Noyes and Kato, *1*, **30**: 318; 08. (45) Noyes and Sammet, *1*, **24**: 944; 02. (46) Pearce and Hart, *1*, **43**: 2483; 21. (46,5) Remy, *237*, **19**: No. 2; 27. (47) Richter, *7*, **80**: 449; 12. (48) Riesenfeld and Reinhold, *7*, **68**: 440; 09. (49) Schneider and Braley, *1*, **45**: 1121; 23.
(50) Smith and MacInnes, *1*, **46**: 1398; 24. (51) Smith and MacInnes, *1*, **47**: 1009; 25. (52) Steele, *7*, **40**: 689; 02. (53) Steele and Denison, *4*, **81**: 456; 02. (54) Stepniczka-Marinkovic, *57*, **36**: 831; 15. (55) Strachan and Chu, *1*, **36**: 810; 14. (56) Straub, *Diss.*, Budapest, 1923. (57) Tower, *1*, **26**: 1039; 04. (58) Velišek, *362*, **20**: 242; 26. (59) Washburn, *1*, **31**: 322; 09.
(60) Washburn and Millard, *1*, **37**: 694; 15. (61) Whetham and Paine, *5*, **81**: 58; 08.

ELECTROLYTIC EMF

Duncan A. MacInnes, Special Editor

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THE CHARACTERISTICS OF STANDARD CELLS AND OF PRIMARY CELLS

M. deKay Thompson

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The Weston Normal Cell and the Weston Unsaturated Cell

Definitions.—The term "Weston Normal Cell" is used here to designate the cell which contains solid crystals of $CdSO_4.\frac{8}{3}H_2O$ and which is used to maintain the standard of electromotive force. The term "Weston Unsaturated Cell" is here used to designate the cell which is made up with a solution of $CdSO_4$ which is saturated at 4°C and contains no excess of solid crystals of the sulfate. This cell is more generally used in practice since it has a lower temperature coefficient than the normal cell.

The Weston Normal Cell

$$Hg|Cd_{12.5\,\%}\ |\ CdSO_4.\tfrac{8}{3}H_2O\ \text{satd.}\ |\ Hg_2SO_4\ \text{paste}\ |\ Hg$$

Emf at 20°*C.*—(*a*) Value in **semi-absolute volts** at 20.00°C, that is, the potential which exists between the terminals of a resistance of one *international* ohm when carrying a current of one *absolute* ampere: 1.01825; average deviation of mean = 0.00002.

This value is the arithmetical mean of the results from the following references: (**1, 23, 25, 34, 50, 57, 62**).

(*b*) Value in **international volts,** when the current through the international ohm is determined by a silver coulometer, the electrochemical equivalent of silver being taken as 1.11800 milligram per coulomb as defined by the International Congress of 1908.

Value recommended by a special technical committee to the International Committee on Electrical Units and Standards: 1.0183 international volt at 20°C (**6**).

Best average value: 1.018274 international volt at 20°C; average deviation of mean = 0.000003.

This average value is the weighted mean from the following references, with assigned weights equal to the square root of the number of observations, since the authors do not compute the precision measure in all cases (**19, 25, 39, 40, 59, 67**); *cf.* (**58**).

The Temperature Coefficient.—$E_t = E_{20} - 0.0000406(t - 20) - 0.00000095(t - 20)^2 + 0.00000001(t - 20)^3$. Adopted by the International Conference on Electrical Units and Standards at London, 1908 (76).

Construction.—Normal cells are nearly always constructed in the H-form proposed by Lord Rayleigh (17, 29, 55, 75). Recently circular forms have been constructed and studied (30, 56).

Heat of the Reaction in the Weston Cell.—$Cd + Hg_2SO_4 + \frac{8/3}{m - 8/3} CdSO_4.mH_2O \rightleftharpoons 2Hg + \frac{m}{m - 8/3} CdSO_4.\frac{8}{3}H_2O$, where m is the number of moles of water per mole of cadmium sulfate in the saturated solution.

The heat of this reaction is 47 561 g-cal_{15} according to thermochemical measurements, and 47 437 from the electromotive force and its temperature coefficient. These values refer to 12.5% Cd in the amalgam (8, 10).

Effect of Pressure on the Emf of the Weston Cell.—*v.* (13, 15).

Influence of Ultra-violet Light on the Emf of the Weston Cell.—*v.* (52).

Effect of Size of Grain of Mercurous Sulfate.—Weston cells made with finely divided mercurous sulfate (grain size of the order of magnitude of 5μ in diameter) have an electromotive force of 40 to 100 microvolt higher than those made with coarse mercurous sulfate (grain size 30 to 360μ). Hysteresis is greatest with coarse, white mercurous sulfate and is less for acid than for neutral cells (72); *cf.* (66, 75).

The Effect of Acidity on the Weston Cell.—For the purpose of making the Weston cell stable for a long time it is sometimes made up with 0.1N sulfuric acid (65). The emf is then 1.0182$_5$ international volt at 20°.

When the Weston cell is made up with acid the decrease in voltage = 0.000 855 × normality of acid (42).

Temperature Coefficients of Cells with Differing Amounts of Acid

$E = E_{20} + \alpha(t - 20) + \beta(t - 20)^2$ (42)

Acidity	0.07_8N	0.40_2N	0.56_6N	0.75_6N
$-10^6\alpha$	42.5	43.6	43.7	45.5
$-10^6\beta$	2.3	2.5	2.6	2.7

The Constancy of Acid Cells (42)

Emf at 20°C of the acid cell (standard: mean of 10 neutral cells, 1.01827 volt at 20°C)

Cell	Acidity: equivalents H_2SO_4 per liter	Date of construction	July 23, 1919	July 29	Aug. 1	Oct. 8	Nov. 4	Mar. 9, 1920	Mar. 25	Oct. 8
		1919	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+
218	0.07_8	July 21	0.00840	0.00836	0.00830	0.00823	0.00822	0.00822	0.00822	0.00822
220	0.40_2	July 21	.00860	.00825	.00810	.00794	.00795	.00794	.00794	opened
221	0.56_6	July 21	.00807	.00802	.00783	.00781	.00780	.00781	.00780	.00780
222	0.75_6	July 21	.00777	.00782	.00772	.00763	.00763	.00761	.00762	.00763
223	0.75_6	July 21	.00732	.00738	.00733	.00761	.00763	.00761	.00763	.00761
226	0.40_2	July 25		.00818	.00809	.00797	.00798	.00794	.00795	.00794

Effect of Composition of the Amalgam on the Emf of Weston Normal Cells.—*v.* (12, 60, 61).

Relation between the Emf and the Concentration of the Amalgam in the Weston Cell (64)

The emf = 1.01823 international volt + the correction given in the table. The corrections are expressed in hundred-thousandths of a volt.

t, °C	Percentage of cadmium in the amalgam							
	1	2	3	4	5	6	7	8
0	−1197	− 365	+ 35	34	35	35	36	36
5		− 580	− 32	35	36	36	37	37
10		− 798	− 246	29	29	30	30	30
15		−1024	− 464	− 79	17	17	18	18
20		−1250	− 684	− 291	− 1	− 1	0	0
25		−1483	− 910	− 507	− 186	− 24	− 24	− 23
30		−1717	−1132	− 729	− 407	−140	− 50	− 49
35		−1959	−1365	− 954	− 628	−362	− 94	− 80
40		−2202	−1594	−1184	− 853	−583	−315	−114
45		−2446	−1837	−1415	−1081	−804	−539	−296

t, °C	Percentage of cadmium in the amalgam								
	9	10	10.5	11	11.5	12	12.5	13	13.5
0	36	36	37	37	39	40	41	47	50
5	37	37	38	38	40	41	42	48	51
10	30	30	31	31	33	34	34	35	38
15	18	18	19	19	21	22	22	25	27
20	0	0	1	1	3	4	4	4	7
25	− 23	− 23	− 22	− 22	− 19	− 18	− 17	− 17	− 16
30	− 49	− 49	− 48	− 48	− 44	− 44	− 43	− 43	− 42

t, °C	Percentage of cadmium in the amalgam								
	9	10	10.5	11	11.5	12	12.5	13	13.5
35	− 79	− 79	− 78	− 78	− 77	− 76	− 76	− 76	− 75
40	−114	−112	−111	−112	−112	−112	−112	−111	−111
45	−148	−146	−145	−145	−146	−145	−145	−144	−144

In the amalgams containing 14 to 20% of cadmium the initial and final values are given for each temperature.

t, °C	Percentage of cadmium in the amalgam							
	14	14.5	15	16	17	18	19	20
0	+238	330	696	486	1098	1290	1560	1610
0	249	457	673	560	1101	1295	1564	1613
5	120	329	537	428	969	1162	1419	1476
5	123	339	533	431	969	1163	1420	1476
10	59	205	390	288	830	1022	1270	1332
10	61	215	387	292	830	1023	1270	1333
15	47	89	239	149	683	870	1124	1187
15	63	115	214	244	643	870	1075	1188
20	13	19	55	72	488	717	922	1036
20	13	19	55	70	488	716	922	1035
25	− 15	− 13	0	0	327	557	760	876
25	− 15	− 13	0	0	327	555	760	877
30	− 42	− 41	− 31	− 40	162	376	594	712
30	− 42	− 41	− 32	− 40	159	372	592	710
35	− 74	− 73	− 71	− 72	− 6	204	423	539
35	− 74	− 73	− 71	− 72	− 7	197	223*	539
40	−111	−110	−108	−109	−108	30	244	361
40	−111	−110	−109	−110	−108	24	241	360
45	−145	−144	−144	−144	−144	−120	+ 60	170
45	−145	−144	−143	−144	−144	−130	+ 48	169

* *Sic!*

ELECTROMOTIVE FORCE OF THE CELL:

Cd amalg. (10%) $|CdSO_4.\frac{8}{3}H_2O|$ Cd amalg. (dilute) [44, 45]

Percentage composition of the dilute amalgam	Emf at 29°C, volt	Temp. coeff., volt per °C
0.25	0.03420	+0.00051
0.50	0.029775	+0.00049
1.11	0.01945	+0.00045(?)
1.25	0.01612	+0.00046
1.73	0.01367	+0.00043
2.19	0.01083	+0.00043
2.83	0.00770	+0.00042
3.47	0.00511	+0.00042

Effect of Age on the Emf of the Weston Normal Cell [63].—Average change in 10 years: −0.000063 volt.

THE WESTON UNSATURATED CELLS

The unsaturated Weston cell is made with a solution saturated at 4°C. It has an average voltage of 1.0187 international volt and a temperature coefficient of less than 0.00001 volt per °C [73]. Each cell is accompanied by a certificate stating its voltage.

UNSATURATED ACID WESTON CELLS

The measurements were made against three well-aged, very constant normal cells made at the National Physical Laboratory, Teddington, England. Their values were assumed to be such that the normal cells made for this investigation would have a value of 1.018054 volt at 25°C. The saturated solutions of cadmium sulfate were made with a 0.015 molal solution of sulfuric acid. The unsaturated solutions were made by adding the number of ml of this solution shown in the table to one liter of the saturated solution.

Composition of cadmium sulfate solutions, electromotive force, and temperature coefficients [71]

Solution number	Cells	Dilute acid added, ml	$CdSO_4$, per cent	Emf at 25°C, volt	$\Delta E/\Delta T$ in mmv per deg			
					15–25°	25–35°	35–40°	40–45°
1	16–20	None	43.22 ± 0.01	1.018270 ± 0.0_58	2.8	2.7	5.0	8.1
2	41–45	2.5	43.12 ± 0.03	1.018374 ± 0.0_57	2.1	2.0	4.7	7.1
3	32–25	5	43.06 ± 0.00	1.018548 ± 0.0_55	1.0	1.1	3.4	5.9
4	26–30	9	43.94 ± 0.01	1.018711 ± 0.0_413	0.1	0.0	2.5	5.4
5	31–35	11	43.90 ± 0.01	1.018788 ± 0.0_57	− 0.1	− 0.3	2.1	4.5
6	36–40	15	42.77 ± 0.04	1.018983 ± 0.0_56	− 1.3	− 1.4	0.7	3.5
7	46–50	22.5	42.63 ± 0.00	1.019343 ± 0.0_57	− 3.5	− 3.6	− 0.9	0.9
8	51–55	30	42.39 ± 0.01	1.019688 ± 0.0_414	− 5.5	− 5.5	− 3.2	−0.6
9	56–60	50	41.84 ± 0.02	1.02095 ± 0.0_43	−13	−13	−10	−8

Neutral cells did not give consistent results for temperature coefficients.

Cadmium Cells with Halide Electrolytes

Cells made in H-form. Measurements refer to an unsaturated Weston cell certified by the Reichsanstalt to have 1.0190 volt at room temperature [46].

1. Cells of the type: $HgCd_{12.5\,\%}$ | CdX_2 satd. | Hg_2X_2 paste | Hg

X	Electromotive force in volt
Cl	$E_t = 0.67180 - 0.000074(t - 18) - 0.0000015(t - 18)^2$
Br	$E_t = 0.55916 - 0.000366(t - 18) - 0.0000046(t - 18)^2$
I	$E_t = 0.41470 - 0.000362(t - 18) - 0.0000003(t - 18)^2$

2. Cells of the type: $HgCd_{12.5\,\%}$ | CdX_2 soln. | Hg_2X_2 paste | Hg

The emf of these cells can be represented by the formula

$$E_{18} = a \log N + b,$$

where N is the number of moles of CdX_2 per liter and a and b are constants:

X	a	b
Cl	−0.04306	0.7017
Br	−0.03953	0.58364
I	−0.03162	0.43338
$\frac{1}{2}SO_4$	−0.02501	1.05125

The Clark Cell

$HgZn_{10\,\%}$ | $ZnSO_4.XH_2O$ satd. X = 7 below 39°; = 6 above 39° | Hg_2SO_4 paste | Hg

Emf at 15°C = 1.4328 int. volt [1, 3, 24, 29, 75].

The Chicago International Electrical Congress of 1893 adopted the value 1.434 international volt as the electromotive force of the Clark Cell at 15°C.

The Temperature Coefficient of the Clark Cell.—$E_t = E_{15} - 0.00119(t - 15) - 0.000007(t - 15)^2$ [31, 32].

Heat of the Reaction in the Clark Cell.—*See* [9, 51].

THE INFLUENCE OF PRESSURE ON THE EMF OF THE CLARK CELL [11, 13, 14, 15, 18]

t, °C	Emf at				
	1 atm.	500 atm.	1000 atm.	1500 atm.	
	First series				
25.0	1.41974	1.42608	1.43223	1.43820	
30.0	1.41368	1.42019	1.42604	1.43168	
35.0	1.40625	1.41290	1.41892	1.42452	
38.0	1.40147	1.40812	1.41427	1.41987	$ZnSO_4.7H_2O$
39.5		1.40566	1.41183	1.41748	
42.0			1.40772	1.41346	
42.5				1.41255	
45.0	1.39400	1.39938	1.40479	1.40983	
50.0	1.38826	1.39387	1.39920	1.40436	$ZnSO_4.6H_2O$
55.0	1.38213	1.38800	1.39338	1.39854	
	Second series				
35.0	1.40625	1.41271	1.41880	1.42452	$ZnSO_4.7H_2O$
42.5				1.41255	
45.0		1.39946	1.40479	1.40982	
50.0	1.38820	1.39383	1.39910	1.40420	$ZnSO_4.6H_2O$
55.0	1.38210	1.38780	1.39314	1.39839	

Temperature Coefficient of the Emf

For cells containing $ZnSO_4.7H_2O$

$P_{atm.}$

1..... $E_1 = 1.43701 - 0.0_3221t - 0.0_4188t^2$

500..... $E_{500} = 1.44105 - 0.0_4840t - 0.0_4206t^2$

1000..... $E_{1000} = 1.44993 - 0.0_3263t - 0.0_4178t^2$

1500..... $E_{1500} = 1.46025 - 0.0_3528t - 0.0_4140t^2$

For cells containing $ZnSO_4.6H_2O$

1..... $E_1 = 1.42811 - 0.0_3407t - 0.0_578t^2$

500..... $E_{500} = 1.43277 - 0.0_3418t - 0.0_572t^2$

1000..... $E_{1000} = 1.44475 - 0.0_3681t - 0.0_546t^2$

1500..... $E_{1500} = 1.44331 - 0.0_3429t - 0.0_570t^2$

The Helmholtz Cell

Zn | $ZnCl_2$ soln., sp. gr. 1.391 | Hg_2Cl_2 | Hg

The reaction is: $Zn + Hg_2Cl_2 = ZnCl_2$ in soln. + 2 Hg; $E_t = 1 + 0.000094(t - 15)$ volt (7, 27, 49).

The Mercury Oxide Cell

Zn | 10% soln. of $ZnSO_4$ | HgO | Hg

The reaction is probably: Zn + HgO = ZnO + Hg, which may be followed by secondary reactions; $E_t = 1.390 - 0.0002(t - 12)$ (7, 22).

The Lead Chloride Cell

HgZn | $ZnCl_2$ soln., sp. gr. 1.157 | $PbCl_2$ | Pb

The reaction is: $Zn + PbCl_2 = ZnCl_2$ in solution + Pb; $E = 0.5$ volt, temperature coefficient negligible (2).

The Cu-Hg Cell

$HgCu_{1.5\text{ to }6\%}$ | $CuSO_4.5H_2O$ satd. | Hg_2SO_4 | Hg (41)

$E_t = 0.34979 - 0.000635(t - 20) - 0.0000024(t - 20)^2$ volt

Total energy of the reaction from emf, 103.5 kj; from thermochemical data, 103.0 kj.

The same cell containing 10 to 12% copper in the amalgam, $E_t = 0.3500 - 0.00064(t - 20) - 0.0000025(t - 20)^2$.

Total energy change of the reaction from thermochemical data, 104.0; from emf, 104.15 kj (47).

The Pb-Hg Cell

Cells of the type:

$HgPb_{x\%}$ | $PbSO_4$ solid | Soluble sulfate | Hg_2SO_4 solid | Hg (37)

Soluble sulfate	x, %	Observed emf, volt at 25°	Average variation of single cell, volt
$Na_2SO_4.10H_2O$*....	3.08 to 3.23	0.96466	0.00002
K_2SO_4.....	3.02	1.0300 to 1.0260	0.01
$Li_2SO_4.H_2O$.....	2.98	0.9615 to 0.9620	0.001
$MgSO_4.7H_2O$.....	2.84	0.9600 to 0.9610	0.001
$NiSO_4.7H_2O$.....	3.50	0.96466	0.00001
$CuSO_4.5H_2O$.....	3.16	0.3489	0.0003
$CdSO_4.\frac{8}{3}H_2O$.....	3.58	0.9520 to 0.9540	0.0012
$ZnSO_4.7H_2O$.....	3.56	0.96480	0.00001
$MnSO_4.5H_2O$.....	3.39	0.96478	0.00001

* For other temperatures: $E_t = E_{25} + 0.000174(t - 25) + 0.00000038(t - 25)^2$. The total energy of the reaction is calculated to be 176.5 kj from electromotive force; 175.05 from thermochemical data.

Low-Voltage Normal Cells (43)

				$E_{20°}$, volt
(*a*) $HgCd_{10\%}$.....	$CdBr_2.4H_2O$	$PbBr_2$	$HgPb_{10\%}$	0.14506
(*b*) $HgCd_{10\%}$.....	$CdCl_2.2\frac{1}{2}H_2O$	$PbCl_2$	$HgPb_{10\%}$	0.14186
(*c*) $HgCd_{10\%}$.....	CdI_2	PbI_2	$HgPb_{10\%}$	0.09835
(*d*) $HgCd_{10\%}$.....	$CdSO_4.\frac{8}{3}H_2O$	$PbSO_4$	$HgPb_{10\%}$	0.08861
(*e*) Cd.....	$CdSO_4$		$HgCd_{10\%}$	0.05160
(*f*) Cd.....	CdI_2		$HgCd_{10\%}$	0.05156
(*g*) Cd.....	$CdCl_2$		$HgCd_{10\%}$	0.05135
(*h*) Cd.....	$CdBr_2$		$HgCd_{10\%}$	0.05012
(*i*) $HgCd_{10\%}$.....	$CdSO_4.\frac{8}{3}H_2O$		$HgCd_{0.5\%}$	0.02980

Temperature coefficient: $E_t = E_{20} + \alpha(t - 20) + \beta(t - 20)$,[2] volt.

Combination	α	β
(*a*)	−0.000370	−0.0000005
(*b*)	−0.000200	−0.0000003
(*c*)	+0.000245	−0.0000001
(*d*)	+0.000548	−0.0000004
(*e*)	−0.000242	0
(*f*)	−0.000248	0
(*g*)	−0.000248	0
(*h*)	−0.000228	0
(*i*)	+0.00050	

Cells of the combinations (*b*) and (*c*) are most reproducible and are constant for a long period.

The LeClanché Dry Cell

Cells 2.5 × 6 in. (63 × 152 mm) are designated as No. 6. Smaller cells are designated as follows (5)

Designation*	Diameter, inches	Height, inches	Diameter, mm	Height, mm
A.....	$\frac{5}{8}$	$1\frac{7}{8}$	16	48
B.....	$\frac{3}{4}$	$2\frac{1}{8}$	19	54
C.....	$\frac{15}{16}$	$1\frac{13}{16}$	24	46
D.....	$1\frac{1}{4}$	$2\frac{1}{4}$	32	57
E.....	$1\frac{1}{4}$	$2\frac{7}{8}$	32	73
F.....	$1\frac{1}{4}$	$3\frac{7}{16}$	32	87

* Includes flat cells of equivalent capacity.

The voltage requirements are those in the following table when measured with a voltmeter of not less than 100 ohm per volt, and having not less than 50 divisions of its scale per volt.

Designation	Nominal dimensions of cell		Minimum voltage
	Diameter, mm	Height, mm	
No. 6.....			1.50
F.....	32	87	1.50
E.....	32	73	1.50
D.....	32	57	1.50
C.....	24	46	1.49
B.....	19	54	1.48
A.....	16	48	1.47

For additional data, *v.* (5).

The electromotive force of the manganese dioxide electrode of dry cells is determined by the hydrogen ion concentration, in the case of Caucasian, Brazilian, and domestic ores. For a tenfold increase in hydrogen ion concentration the electrode potential increases from 0.06 to 0.08 volt. Chemically prepared dioxide is apparently free from this concentration effect (28).

Assumed Reactions of the LeClanché Cell

Negative pole: $Zn + 2F + 2Cl^- = ZnCl_2$.

Positive pole:

$$2NH_4^+ + 2MnO_2 = 2NH_3 + H_2O + Mn_2O_3 + 2F$$
$$2NH_3 + ZnCl_2 = Zn(NH_3)_2Cl_2$$

Other oxides of manganese probably form.

Net reaction: $Zn + 2NH_4Cl + 2MnO_2 = Zn(NH_3)_2Cl_2 + Mn_2O_3 + H_2O$.

The reaction at the positive pole may also be considered to take place as follows (20, 36, 68):

$$MnO_2 + 2H_2O \rightleftarrows Mn^{++++} + 4OH^-$$
$$Mn^{++++} = Mn^{++} + 2F$$
$$Mn^{++} + 2OH^- = Mn(OH)_2$$

Net reaction: $MnO_2 + 2H_2O = Mn(OH)_2 + 2OH^- + 2F$.

EFFECTS OF TEMPERATURE ON DRY CELLS (4)

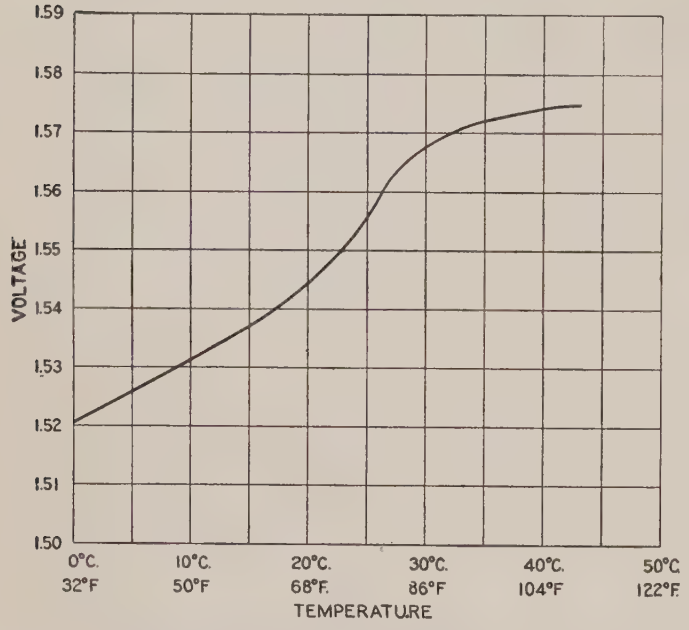

FIG. 1.—Effect of temperature on open-circuit voltage of dry cells.

Mean of measurements on 16 cells, No. 6 size, paper-lined construction, including four different brands. The cells were kept at fixed temperatures 24 hours before being measured.

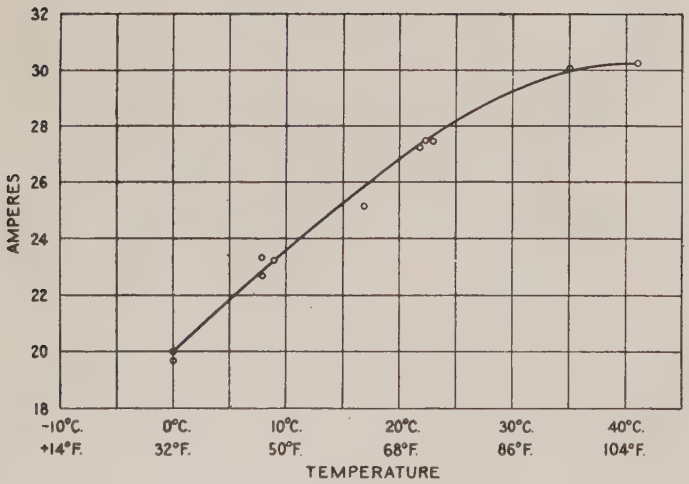

FIG. 2.—Effect of temperature on short-circuit current.

Mean values for a group of six cells maintained at each of the temperatures indicated for at least 24 hours prior to the measurements. The temperatures were taken in the following order; 22, 0, 22.5, 8, 0, 21.8, 35, 41, 8, 16.8, and 9°C.

EFFECT OF TEMPERATURE ON THE SHORT-CIRCUIT CURRENT OF DRY CELLS STORED FOR 10 WEEKS ON OPEN CIRCUIT (PRITZ (53))

Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks	Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks
5	4.4	55	52.0
25	10.0	65	71.0
35	19.0	75	98.0
45	25.0		

Recent experiments show that the measurements of Pritz for cells stored at 25°C are approximately correct for dry cells when new, but the rate of decrease of short-circuit current becomes less as the age of the cell increases; the total decreases during a year at room temperature being about 25%.

HOURS OF SERVICE OF NO. 6 DRY CELLS DISCHARGED TO 0.5 VOLT AT VARIOUS RATES AND TEMPERATURES (48, 53)

Temp., °C	Service at various resistances of external circuit in ohms			
	2 ohm, hr	4 ohm, hr	8 ohm, hr	16 ohm, hr
0	40	80	270	560
25	60	94	260	700
50	70	160	350	650
75	65	158	315	615

HOURS OF SERVICE OF DRY CELLS, NO. 6 SIZE, DISCHARGED TO 0.6 VOLT AT FIXED RATES OF CURRENT AND AT VARIOUS TEMPERATURES

Average of results of tests made on three standard makes of dry cells of paper-lined construction

Temp., °C	Service at various rates of discharge in ampere				
	0.1 amp., hr	0.25 amp., hr	0.50 amp., hr	0.75 amp., hr	1.00 amp., hr
0	136	40	14	7	5
25	220	64	24	13	9
40	300	94	31	18	11

INITIAL WORKING VOLTAGE OF NO. 6 DRY CELL (21)

Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage	Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage
0.00	42.9*	0.00*	4	0.370	1.48
.01	32.0*	.32*	8	.185	1.48
.02	26.5*	.53*	16	.092	1.48
.04	18.5*	.74*	32	.046	1.48
.08	12.0*	.96*	64	.023	1.49
$\frac{1}{8}$	8.8	1.10	128	.0117	1.50
$\frac{1}{4}$	5.1	1.28	256	.0059	1.52
$\frac{1}{2}$	2.76	1.38	512	.0030	1.52
1	1.45	1.45	∞	.0000	1.53
2	0.735	1.47			

* Estimated by extrapolation.

LeClanché Dry Cell.—*(Continued)*

HOURS OF SERVICE FOR NO. 6 PAPER-LINED DRY CELL AT ROOM TEMPERATURE, THROUGH CONSTANT RESISTANCE (21)

Figures in parentheses are interpolated

Cell discharged	Cut-off voltage	Total life in hours for various ohms resistance of circuit, ohm														
		⅛	¼	½	1	2	4	8	16	32	64	128	256	512	1024	1792
Continuously (1)	1.2		0.02	0.13	0.70	2.2	9.1	47	115	390	1 050	2 780	4 220	6 350	7 850	9 120
	1.0	0.01	.21	.95	3.7	11.1	32.5	89	233	650	1 560	3 200	4 800	6 850	9 720	10 740
	0.8	.14	.76	2.3	7.4	20.7	53.0	119	304	740	1 750	3 350	5 100	7 300	10 200	11 500
	.6	.50	1.9	5.1	12.5	36.3	75.0	184	383	805	2 470	3 500	5 220	7 550	10 570	11 800
	.4	1.4	3.8	8.5	21.4	49.8	100.0	227	462	890	2 530	3 650	5 350	7 700	10 970	12 100
30 minutes every hour (2)	1.2				1.0	4.0	15.0	40	210	550	1 370					
	1.0			(1.1)	5.5	13.0	37.0	120	320	810	1 570					
	0.8	(0.2)	(0.8)	(3.0)	9.0	26.0	61.0	190	375	920	1 630					
	.6	(0.7)	(2.0)	(5.6)	15.5	43.0	87.0	230	420	1 000	1 680					
	.4	(1.5)	(4.0)	(9.7)	25.0	58.0	120.0	280	470	1 040	1 750					
15 minutes every hour (3)	1.2				1.0	5.0	13.0	90	240	580	1 225					
	1.0		0.17	1.2	5.0	17.0	47.0	157	370	815	1 275					
	0.8	0.31	1.0	3.0	10.5	40.0	80.0	195	445	875	1 325					
	.6	.91	2.3	5.1	16.5	74.0	100.0	223	500	920	1 370					
	.4	2.0	4.3	11.0	29.0	89.0	122.0	264	560	965	1 420					
5 minutes every hour (4)	1.2			0.18	2.5	10.5	45.0	115	292	508						
	1.0		0.34	2.0	7.5	28.0	75.0	166	360	542						
	0.8	0.21	1.2	4.1	13.5	40.0	93.0	201	385	567						
	.6	.75	2.3	6.4	20.0	50.0	114.0	224	403	602						
	.4	1.9	4.3	11.0	33.0	62.0	128.0	236	416	625						
2 minutes every hour (5)	1.2			0.53	3.5	22.0	56.0	152	207	272						
	1.0	0.06	0.53	2.3	13.0	35.0	78.0	167	216	288						
	0.8	.28	1.3	5.4	19.5	44.0	90.0	194	224	307						
	.6	.72	3.0	10.0	28.0	59.0	103.0	209	231	333						
	.4	1.8	6.0	15.0	36.0	68.0	109.0	217	240							
½ minute every hour (6)	1.2			2.0	8.7	22.0	42.0	70								
	1.0		1.6	6.0	15.7	29.0	46.0	76								
	0.8	0.80	3.7	8.5	17.7	31.0	48.0	80								
	.6	1.9	6.5	12.0	20.0	33.0	50.0	82								
	.4	5.2	10.3	16.0	23.0	36.0	52.0	85								
5 minutes every 10 minutes (7)	1.2			0.14	1.5	5.0	20.0	40	220	530	1 280	2 550				
	1.0		0.42	1.3	6.0	14.5	45.0	115	340	795	1 580	2 800				
	0.8	0.45	1.5	3.3	9.5	28.0	70.0	170	410	930	1 670	2 850				
	.6	1.3	3.0	6.0	16.5	45.0	105.0	220	460	1 010	1 730	2 875				
	.4	2.3	4.8	9.0	26.0	60.0	135.0	270	520	1 100	1 810	3 000				
30 minutes every 6 hours (8)	1.2				1.3	15.0	40.0	107	309	460						
	1.0				9.5	29.0	75.0	137	353	505						
	0.8				17.0	40.0	93.0	186	367	545						
	.6				24.0	48.0	102.0	216	381	590						
	.4				30.0	56.0	111.0	228	395	625						
5 minutes every 6 hours (9)	1.2			0.2	4.1	17.0	56.0									
	1.0		0.24	2.9	11.2	32.0	61.0									
	0.8	0.34	1.7	6.7	16.3	37.0	63.0									
	.6	.9	3.5	10.2	21.0	42.0	65.0									
	.4	2.8	6.5	14.0	26.0	47.0	82.0									

The Féry Zinc-Carbon Cell

Similar to the LeClanché but contains no manganese dioxide. The carbon electrode is cylindrical and is made of specially prepared carbon. A horizontal plate of zinc is at the bottom of the carbon cylinder and is insulated from it. A test cell mounted in a vessel 10 cm square and 22 cm high, containing 1 liter of water + 125 g of ammonium chloride and a zinc plate weighing 160 g yielded 125 ampere hours (69).

Caustic Soda Cells

REACTIONS OF THE CAUSTIC SODA CELL (20)

Negative pole: $Zn + 2F + NaOH + 2OH^- = NaHZnO_2 + H_2O$.

Positive pole: $2H^+ + 2CuO = H_2O + Cu_2O + 2F$ (also: $Cu_2O + 2H^+ = H_2O + 2Cu + 2F$).

Net reaction: $Zn + 2CuO + NaOH = NaHZnO_2 + Cu_2O$.

The following graphs show performance under different conditions of temperature and concentration of electrolyte (36.1).

Caustic Soda Cells.—(*Continued*)

CuO | 20 to 25% solution of NaOH covered with oil | Zn amalg.

This cell is made in capacities from 200 to 1000 ampere hours.

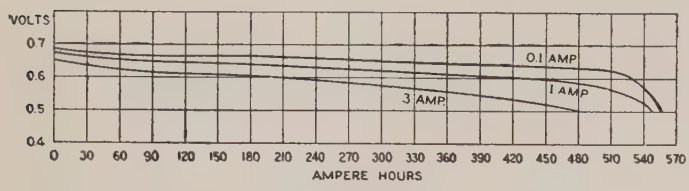

FIG. 3.—Graphs showing the voltage of a 500-ampere hour cell during discharge at 23°C. (Private Communication.)

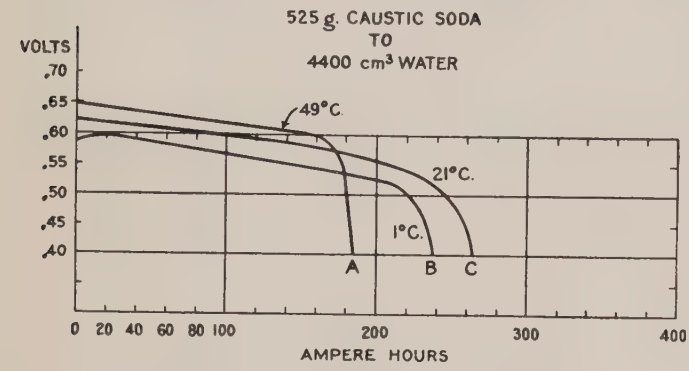

FIG. 4.—Performance of cell containing 525 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

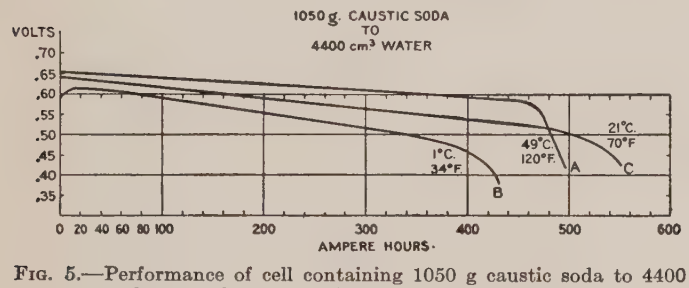

FIG. 5.—Performance of cell containing 1050 g caustic soda to 4400 cm³ water, the normal concentration. Current constant at 3 ampere.

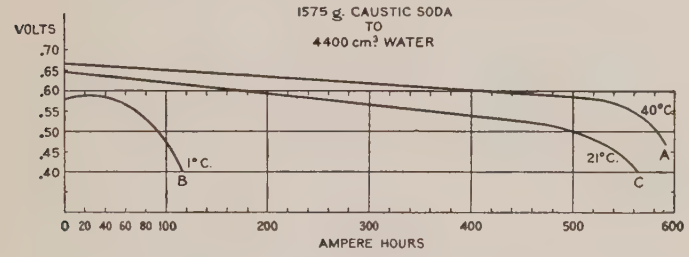

FIG. 6.—Performance of cell containing 1575 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

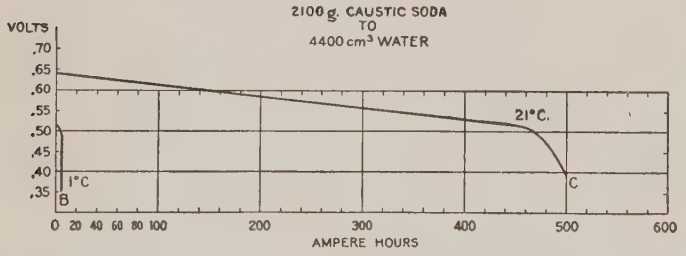

FIG. 7.—Performance of cell containing 2100 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

The Nyberg cell: Amalgamated Zn | 10% NaOH | Porous C

Voltage 1.00 to 1.18 for currents of 1 to 0.1 ampere. For a volume of 1000 cm³ and weight 1300 g the maximum capacity is 210 watt-hr [38].

The Daniell Cell

Zn | $ZnSO_4$ or H_2SO_4 soln. | $CuSO_4$ soln. | Cu

The two electrolytes are separated by a porous cup, or by difference in density in the "gravity" type of cell. E varies from 1.07 to 1.14 volt.

The reaction is: $Zn + CuSO_4$ in solution = $ZnSO_4$ in solution + Cu [16].

The Grove and Bunsen Cells

HgZn | 1 vol. H_2SO_4 to $12H_2O$ | Conc. HNO_3 | Pt

E = 1.9 to 2 volt. The two acids are separated by a porous cup.

The Bunsen cell is the Grove cell with platinum replaced by carbon.

The Poggendorff Cell

HgZn | Dil. H_2SO_4 | Conc. soln. of $Na_2Cr_2O_7$ or $K_2Cr_2O_7$ + H_2SO_4 | C

Reaction at negative pole: $3Zn + 6F + 3SO_4^{--} = 3ZnSO_4$ which is the same for all cells with zinc dipping into sulfuric acid.

At the positive pole: $Na_2Cr_2O_7 + H_2SO_4 = Na_2SO_4 + H_2O + 2CrO_3$.

$$2CrO_3 + 3H_2SO_4 + 6H^+ = 6H_2O + Cr_2(SO_4)_3 + 6F$$

Net reaction: $3Zn + 7H_2SO_4 + Na_2Cr_2O_7 = 3ZnSO_4 + Na_2SO_4 + Cr_2(SO_4)_3 + 7H_2O$.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ayrton, Mather and Smith, *62*, **207**: 463; 08. (2) Bouty, *51*, **9**: 229; 80. (3) Bronson and Shaw, *121*, **66**: 698; 11. (4) Bureau of Standards, *365*, **No. 79**; 23. (5) Bureau of Standards, *365*, **No. 139**; 27. (6) Bureau of Standards, *Misc. Pub.*, **16**: 9, 206; 12. (7) Carhart and Schoop, *Die primären Elemente*. Halle, Knapp, 1895. (8) Cohen, *7*, **34**: 621;00. (9) Cohen, *7*, **76**: 75; 11.

(10) Cohen, Helderman and Moesveld, *7*, **96**: 259; 20. (11) Cohen, Inouye and Euwen, *7*, **75**: 1; 11. (12) Cohen and Moesveld, *7*, **95**: 285; 20. (13) Cohen and Sennige, *83*, **5**: 269; 09. (14) Cohen and Sennige, *7*, **67**: 432; 09. (15) Cohen and Sennige, *7*, **67**: 536; 09. (16) Cooper, *Primary batteries*. London, Benn, 1916. (17) Eppley, *143*, **201**: 17; 26. (18) Euwen, *Diss.*, Utrecht, 1911. (19) Feringer, *Electritschestvo*, **35**: 260; 14.

(20) Foerster, *Elektrochemie wässeriger Lösungen*. Leipzig, Barth, 1922. (21) Gillingham, *78*, **34**: 297; 18. (22) Gouy, *51*, **7**: 532; 88. (23) Guillet, *126*, **8**: 535; 08. *34*, **153**: 718; 11. (24) Guthe, *31A*, **2**: 33; 06. (25) Haga and Boerema, *64P*, **13**: 587; 10. (26) Haga and Boerema, *18*, **3**: 324; 14. (27) Helmholtz, *76*, **1882**: 22. (28) Holler and Ritchie, *51*, **No. 364**; 20. (29) Hulett, *2*, **32**: 257; 11.

(30) Ishibashi, *338*, **No. 113**; 22. (31) Jaeger and Kahle, *8*, **65**: 926; 98. (32) Jaeger and Kahle, *243*, **18**: 161; 98. (33) Jaeger and Wachsmuth, *8*, **59**: 575; 96. (34) Janet, Laporte and Jouaust, *126*, **8**: 459; 08. (35) Janet, Laporte and Jouaust, *34*, **153**: 718; 11. (36) MacInnes, *78*, **29**: 315; 16. (36.1) Martus, *78*, **53** (preprint); 28. (37) Mellon and Henderson, *1*, **42**: 676; 20. (38) Nyberg, *9*, **30**: 549; 24. (39) Obata, *219*, **8**: 437; 16.

(40) Obata, *219*, **9**: 416; 18. (41) Obata, *219*, **2**: 223; 20. (42) Obata, *219*, **2**: 232; 20. (43) Obata, *219*, **3**: 64; 21. (44) Obata, *219*, **3**: 136; 21. (45) Obata, *338*, **No. 100**; 21. (46) Öholm, *426*, **41**: 3; 12. (47) Öholm, *147*, **5**, No. 4; 19. (48) Ordway, *78*, **17**: 358; 10. (49) Ostwald, *7*, **1**: 403; 87.

(50) Pellat, *126*, **8**: 573; 08. *34*, **153**: 718; 11. (51) Pollitzer, *7*, **78**: 374; 11. (52) Pouguet, Segol and Segol, *34*, **157**: 1522; 13. (53) Pritz, *78*, **19**: 31; 11. (54) Rayleigh, *62*, **176**: 781; 86. (55) Rayleigh and Sidgwick, *62*, **175**: 442; 84. (56) Rodman and Spooner, *114*, **18**: 65; 21. (57) Rosa, Dorsey and Miller, *31A*, **8**: 269; 11. (58) Rosa and Vinal, *197*, **3**: 59; 17. (59) Rosa, Vinal and McDaniel, *31A*, **10**: 475; 14.

(60) Schulze, *7*, **105**: 177; 23. (61) Schulze, *243*, **43**: 81: 23. (62) Shaw, *62*, **214**: 147; 14. (63) Shaw and Reilley, *69*, **13 III**: 171; 19. (64) Smith, *3*, **19**: 250; 09. *67*, **22**: 11; 09. *121*, **64**: 943; 09. (65) Smith, *Rept. National Physical Lab.*, **1919**: 49. (66) von Steinwehr, *243*, **25**: 205; 05. (67) von Steinwehr, *243*, **33**: 353; 13. (68) Thompson and Crocker, *78*, **27**: 155; 15. (69) Troller, *Brass World*, **18**: 24; 22.

(70) Vinal and Bates, *31A*, **10**: 425; 14. (71) Vosburgh and Eppley, *1*, **45**: 2071; 23. (72) Vosburgh and Eppley, *1*, **46**: 104; 24. (73) Weston Electrical Instrument Corpn., Newark, N. J., *0*. (74) Wolff, *31A*, **5**: 309; 08. (75) Wolff and Waters, *31A*, **4**: 1; 07. (76) Anon., *121*, **62**: 101; 08.

THE POTENTIALS OF ELECTRODE CELLS

CHARLES P. SMYTH

The term "electrode cell" as employed in this section signifies a cell whose emf is determined solely or chiefly by differences in concentration or physical condition of some atomic or molecular species in the electrode. The cells are arranged in alphabetical order of the symbols of the most important chemical element of the cell. In most instances the cell is given by literature reference only and only reversible cells have been included.

Le terme "electrode cell" tel qu'il est employé dans cette section, signifie une cellule dont la fem est déterminée uniquement ou principalement par les différences de concentration ou de conditions physiques d'une espèce atomique ou moléculaire, dans l'électrode. Les cellules sont arrangées dans l'ordre alphabétique des symboles de l'élément chimique le plus important de la cellule. Dans la plupart des cas, la cellule n'est donnée que par une référence bibliographique et les cellules reversibles ont seules été mentionnées.

Der Ausdruck "electrode cell," wie er in diesem Abschnitt verwendet wird, bezeichnet eine Zelle deren elektromotorische Kraft ausschliesslich oder hauptsächlich durch die Differenz in den Konzentrationen oder in den physikalischen Zustand einiger atomarer oder molekularer Stoffe in der Elektrode bestimmt ist. Die Zellen sind in alphabetischer Reihenfolge der Symbole des wichtigsten Elementes der Zelle, angeordnet. In vielen Fällen ist die Zelle nur durch die Literaturstelle angegeben und es werden nur reversible in Betracht gezogen.

Il termine "electrode cell" come viene impiegato in questo capitolo significa una cella la cui fem è determinata in modo esclusivo o per la massima parte, da differenze di concentrazione o di condizione fisica di qualche specie molecolare o atomica nell'elettrodo. Le celle sono disposte in ordine alfabetico del simbolo dell'elemento più importante delle celle stesse. Nella maggior parte dei casi la cella è indicata con la citazione bibliografica, e solo le celle reversibili sono state incluse.

ABBREVIATIONS

Ac	Acetate radical.
E_t	Emf at t, °C.
mv	Millivolts.
M	Molal.
M_x	The element M in the amount x wt. % in the electrode.
N	Normal.
satd.	Saturated.

ABRÉVIATIONS

Ac	Radical acétate.
E_t	Fem à t, °C.
mv	Millivolts.
M	Molal.
M_x	L'élément M dans la proportion x % poids dans l'électrode.
N	Normal.
satd.	Saturé.

ABKÜRZUNGEN

Ac	Acetat-Radikal.
E_t	Elektromotorische Kraft bei t, °C.
mv	Millivolt.
M	Molar.
M_x	Das Element M ist zu x Gew. % in der Elektrode vorhanden.
N	Normal.
satd.	Gesättigt.

ABBREVIAZIONI

Ac	Radicale acetico.
E_t	Fem a t, °C.
mv	Millivolts.
M	Molale.
M_x	L'elemento M nella quantità x in peso % nell'elettrodo.
N	Normale.
satd.	Saturo.

AQUEOUS SOLUTIONS

Ag

Ag | AgCl | 0.1N KCl | HgCl | Hg+
$E_{25} = 45.1 \pm 0.5$ mv; $10^3 dE/dP = (2.66 \pm 0.2)$ mv/atm. (99)

Ag(colloidal) | $AgNO_3$ | Ag(cryst.)+
$E_{25} = 25 \pm 5$ mv (92)

Ag(powder) | 0.1N $AgNO_3$ | Ag(compact) (62)

Ag_xPd | Ag_2SO_4 | Ag (61)

Ag_xSe or Te | $N/7$ $AgNO_3$ | Ag (68)

Ag_xSe | $AgNO_3$(satd.) | Ag (64)

Au

Au(var. treatments) | $AuCl_3$ | KCl | HgCl | Hg (28)

Au_xSn | $SnCl_4$ | $AuCl_3$ | Au (54)

Ba

Ba_xHg | $Ba(OH)_2$(satd.) | KCl | N KCl | HgCl | Hg (90)

Bi

Bi_x(x = 1.6 to 93.9 at. %)Hg | $Bi(NO_3)_3$ | Bi (66, 67)

Cd

Cd_xAg | N $CdSO_4$ | Cd (51, 90.5)

Cd_xAu | N $CdSO_4$ | Cd (88)

Cd_xBi | N $CdSO_4$ | Cd (29, 35)

Cd_xBi_yPb | N $CdSO_4$ | Cd (48)

Cd_xCu | N $CdSO_4$, N H_2SO_4 | Cd (68)

Cd_xHg | $CdSO_4$ | Cd_yHg
Precise determinations of E and dE/dt for a number of dilute amalgams (80, 81); *cf.* (9, 16, 38)

Cd_xHg | $CdSO_4.\frac{8}{3}H_2O$, Hg_2SO_4 | Hg (93)
v. p. 312

Cd_xHg | $CdSO_4.\frac{8}{3}H_2O$ | Cd_yHg
v. p. 312

Cd_xHg | N $CdSO_4$ | Cd (*v.* p. 312)

Cd_xHg | $CdSO_4$ | $Cd_{\alpha, \beta \text{ or } \gamma}$ (14, 15)

Cd_xPb | N $CdSO_4$ | Cd (29, 35)

Cd_xSb | $CdSO_4$ | Cd (44)

Cd_xSn | $CdSO_4$ | Cd (29, 35)

Cd_xTl | M $CdSO_4$ or TlCl(satd.) | Tl_yHg (50)

Ce

Ce_xFe | 0.3N $CeCl_3$, 0.2N $FeSO_4$ | N KCl | HgCl | Hg (10)

Ce_xFe | 0.3N $CeCl_3$, 0.2N $ZnCl_2$ | N KCl | HgCl | Hg (10)

Co

Co_xM | N $CoSO_4$ | Co (20, 21, 22, 23, 24, 26)
M = Ag, As, Bi, Cu, Pb, Sb

Cu

Cu_xAg | N $CuSO_4$ | Cu (35)

Cu_xAu | 0.5M[$CuSO_4$ or $Cu(NO_3)_2$] | Cu (95)

Cu_xHg | $CuSO_4$ | Cu_yHg (82, 83)

Cu_x (x = 1 to 16%)Hg | $CuSO_4$(satd.), Hg_2SO_4 | Hg+
$E_{25} = 347.2 \pm 0.2$ mv (11)

$+Cu_{12\%}$ Hg | $CuSO_4$(dil.) | Cu
E (mv $\pm$ 1) = 6.5 at 0°; = 5.5 at 25° (11)

Cu_xP | N $CuSO_4$ | Cu (37)

Cu_xPd | 0.5M $CuSO_4$ | Cu (61)

Cu_xSe | $CuSO_4$ | Cu (64)

Cu_xTe | N $CuSO_4$ | Cu (68)

Fe

Fe(var. treatments) | $FeSO_4$ | N KCl, HgCl | Hg

Other similar cells (1, 28, 76, 77). A magnetic field has a negligible effect upon the potential of Fe, but lowers the potential of hydrogen occluded in Fe, the amount of the lowering being approximately proportional to the intensity of the magnetic field and to the amount of the hydrogen overvoltage (84); *cf.* (74, 103).

H_2

$H_2(p)$ | 0.1N HCl | HgCl | Hg+ (33)

$p_{atm.}$	E(mv)	$p_{atm.}$	E(mv)	$p_{atm.}$	E(mv)
1.0	399.0	439.3	480.4	754.4	490.3
37.9	445.6	556.8	484.4	862.2	493.2
51.6	449.6	568.8	485.0	893.9	493.8
110.2	459.6	701.8	489.1	974.5	496.3
204.7	468.3	717.8	489.9	1035.2	497.5
386.6	478.4	731.8	489.3		

In

In_xHg | $In_2(SO_4)_3$ | In_yHg

Dilute amalgams; $E \pm 0.005$ mv at 0 and 30° (86, 87)

Na

Na_xHg | 0.5N NaOH | Na_yHg

Dilute amalgams; values of $E_{25} \pm 0.08$ mv and of dE/dt (78)

Ni

Ni_xCu | N $NiSO_4$ | Ni (100)

Ni_xCu | yN $NiSO_4 + (1-y)N$ $CuSO_4$ | N KCl | HgCl | Hg (31)

Pb

Pb_xM | N $Pb(NO_3)_2$ | Pb

M = Ag, As, Bi, Cu, Hg, Pd, Pt, Sb, Te (66, 67, 68, 70, 71, 72, 73)

Pb_xBi | $PbCl_2$(satd.) | Pb

Dilute and concentrated alloys; $E \pm 0.2$ mv at room temp. (91)

Pb_xHg | $PbAc_2$, HAc | Pb_yHg

Dilute amalgams; $E \pm 0.01$ mv at 0 and 30° (82, 83)

Pb_xHg | $PbCl_2$ | 0.5N NaCl, 0.5N HCl | HgCl | Hg

$E \pm 0.1$ mv at 0.2, 15.5 and 29.2° (2)

$+Pb_{5\%}$ Hg | M? [$PbAc_2$ or $Pb(ClO_4)_2$] | Pb

$E_{25} = 5.7 \pm 0.1$ mv; $dE/dt = 0.02$ mv/°C (30)

Pb_xHg | $PbCl_2$(satd.) | HgCl | Hg+ (I)
$+Pb_xHg$ | $PbCl_2$(satd.) | Pb (II)
$+Pb_{1\%}Hg$ | $PbCl_2$(satd.) | $Pb_{30\%}Hg$ (III) } (98)

x, %	Type	°C	E, mv	±	$10^3 dE/dP$, mv/atm.
30	I	15	529.85	0.2	3.96±0.16
30	I	25	530.62	0.2	3.90±0.16
1	I	25	525.6	0.1	2.98±0.2
30	II	25	24.2	1	1.0 ±0.2
	III	25	7.5	0.5	0.72±0.1

Pb_xSe | $Pb(NO_3)_2$(satd.) | Pb

Also with $PbCl_2$(satd.) (64)

Sb

Sb(expl.) | $SbCl_3$ | Sb(ord.)+

$E_{15} = 18 \pm 1$ mv (18)

Sb_xCu | $SbCl_3$, HCl | Sb (3)

Sb_xSe | 0.1N $SbCl_3$, 2N HCl | Sb (53)

Sb_xSe | $SbCl_3$, HCl | Sb

Effect of light on Sb_xSe (63, 65)

Sn

Sn(gray) | $(NH_4)_2SnCl_6$ | Sn(white) (12)

Sn_xAg | $SnCl_2$(satd.) | Sn (35)

MSn_x | N H_2SO_4 or KOH | Sn

M = Ag, As, Au, Bi, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Te, or Cu + Ag (68, 69, 70)

Sn_xBi | $SnCl_2$ | Sn (91)

Sn_xCo | N $CoSO_4$ | Co (25)

Sn_xHg | 0.5N $SnCl_2$ | Sn_yHg

0 and 30°; $E \pm 0.005$ mv (86, 87); *cf.* (36)

Sn_xNi or Sb | $SnCl_2$ | Sn (69, 70)

Sn_xPb | Pb and Sn salts | HgCl | Hg (60)

Tl

Tl_xBi | TlCl(satd. at 15°) | Tl (50)

Tl | TlCl(satd.) | N KCl | HgCl | Hg+

$E_{25} = 729.0 \pm 0.1$ mv; $dE/dt = 0.75$ mv/°C (39)

$Tl_{55\%}Hg$ | TlCl(satd.) | N KCl | HgCl | Hg+

$E_{25} = 726.2 \pm 0.3$ mv; $dE/dt = 0.71$ mv/°C (39)

Tl_xHg | Tl_2SO_4 | Tl_yHg

Accurate values 0, 15, 20, 30° for wide variation of x and y (79, 85, 86, 87); *cf.* (2)

Tl_xPb | TlCl(satd.) | Tl (4, 50)

Also with Sb and Sn

Zn

MZn_x | $ZnSO_4$ | Zn

M	Lit.	M	Lit.	M	Lit.
Ag.....	(35, 45, 68)	Co.....	(27)	Ni.....	(101)
Ag + Pb...	(45)	Cd.....	(68)	Pb.....	(29, 46)
Au.....	(68)	Cu.....	(89)	Pb + Sn..	(47)
Bi.....	(29, 35, 49)	Fe.....	(102)	Sb.....	(35, 69)
Bi + Sb....	(49)	Hg.....	*v. infra*	Sn.....	(29, 35)

Zn_xCu | N $Na_2SO_4 + yN$ $ZnSO_4 + (1-y)N$ $CuSO_4$ | N KCl | HgCl | Hg (94)

Zn_xHg | $ZnSO_4$ | Zn_yHg

Accurate values at 0, 0.2, 12.1, 15, 25, 35, 50°; wide range of x and y (13, 19, 34, 59, 82, 83)

$+Zn_{0.6\%}Hg$ | $ZnSO_4$ / $ZnCl_2$ | $Zn_{1.2\%}Hg$

E (mv) $= 6.964(1 + 0.00443t)$; range, $t = 10$ to 50° (9)

$Zn_{10\%}Hg$ | $ZnSO_4.7H_2O$, Hg_2SO_4 | Hg+

$E_{25} = 1419.99 \pm 0.05$ mv; $10^3\, dE/dP = -12.2 \pm 0.3$, mv/atm. (17)

$Zn_{7\%}Hg$ | $ZnCl_2$ (p %), MCl | M+ (99)

M	p, %	E_{25}, mv	±	$10^3\, dE/dP$, mv/atm.
Ag.....	35.03	958.72	0.05	−1.22±0.2
Ag.....	65.59	846.66	0.1	−2.66±0.2
Hg.....	35.03	1005.61	0.05	+1.54±0.15
Hg.....	65.59	892.8	0.2	+0.04±0.03

Non-Aqueous Liquids

$Ca_{0.0546\%}Hg$ | CaI_2 in pyridine / $CaCl_2$ in alcohol | $Ca_{0.11\%}Hg$ (5)

For similar cells in CH_3OH at 80°C, *v.* (6)

Ca_xHg | CaI_2 | $AgNO_3$ | Ag

In pyridine (7)

Cd_xBi | $CdCl_2$ in LiCl + KCl + KOH | Cd

$E \pm 2$ mv at 431, 479, 533 and 577°; same with Sn (97)

$+K_{0.2216\%}Hg$ | KI in ethylamine | K

$E_{25} = 1048.1 \pm 0.3$ mv; $dE/dt = \pm 0.272$ (56)

$+Li_{0.0144\%}Hg$ | LiCl in pyridine | $Li_{0.025\%}Hg$

$E_?$ = 16.9 ± 0.2 mv; LiCl almost satd. (82, 83)

$+Li_{0.035\%}Hg$ | LiI in pyridine | Li

$E_{25} = 950.2 \pm 1$ mv; $dE/dt = 0.322$; LiCl almost satd. (57)

Mg_xHg | 0.35M $MgCl_2$ | 0.35M $MgCl_2$ | HgCl | Hg

In methyl alcohol at −80°C (8)

Mg_xHg | MgI_2 | $AgNO_3$ | Ag in pyridine (8)

$+Na_{0.206\%}Hg$ | NaI in ethylamine | Na

$E_{25} = 845.6 \pm 0.1$ mv; $dE/dt = 0.0408$ (58)

Na_xHg | 0.1N NaI in pyridine | Hg (41)

Na_xHg | NaOH in 95% alcohol | Hg_2O | Hg (32)

Pb_xHg | $PbBr_2$(solid) | Pb_yHg, 263 to 403°K (40)

Pb_xZn | y $ZnCl_2 + (1-y)$ $PbCl_2$ | $PbCl_2$ | Pb, 515° (75)

$+Rb_{0.217\%}Hg$ | RbI in $C_2H_5NH_2 + NH_3$ | Rb

$E_{25} = 1074.5 \pm 1$ mv (55)

Sn_xHg | $SnCl_2$ in pyridine | Sn_yHg
$E \pm 0.4$ mv at 25 and 50°; x, 0 − 100% (36)
Zn_xCd | $ZnCl_2$ in LiCl + KCl + KOH | Zn
$E \pm 0.2$ mv at 436, 464, 541 and 572° (97)
Zn_xCu | $ZnCl_2$ | Zn (89)
Zn_xSb | $ZnCl_2$ | Glass | Zn (96)
Zn_xSn | $ZnCl_2$ in LiCl + KCl + KOH | Zn
$E \pm 0.2$ mv at 431, 466, 537, 570° (97)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Arndt, *192*, **7**: 627; 10. (2) Babiński, *Diss.*, Leipzig, 1906. (3) Baikov, *in B87*, **II, Pt. I**: 145; 21. (4) Bekier, *Chemik Polski*, **15**: 119; 17. (5) Cady, *50*, **2**: 551; 98. (6) Cambi, *22*, **23 II**: 606; 14. (7) Cambi, *22*, **24 I**: 817; 15. (8) Cambi, *22*, **24 I**: 932; 15. (9) Carhart, *31A*, **7**: 475; 11. (10) Clotofski, *93*, **114**: 1; 20. (11) Cohen, Chattaway and Tombrock, *7*, **60**: 706; 07. (12) Cohen and van Eijk, *7*, **30**: 601; 99. (13) Cohen and van Ginneken, *7*, **75**: 437; 10. (14) Cohen and Heldermann, *64P*, **17**: 638; 14. (15) Cohen and Heldermann, *64V*, **23**: 60; 14. (16) Cohen and Kruyt, *7*, **65**: 359; 09. (17) Cohen and Sinnige, *7*, **67**: 513; 09. (18) Cohen and Strengers, *7*, **52**: 129; 05. (19) Crenshaw, *50*, **14**: 158; 10. (20) Ducelliez, *34*, **150**: 98; 10. (21) Ducelliez, *27*, **7**: 196; 10. (22) Ducelliez, *27*, **7**: 199; 10. (23) Ducelliez, *27*, **7**: 201; 10. (24) Ducelliez, *27*, **7**: 202; 10. (25) Ducelliez, *27*, **7**: 205; 10. (26) Ducelliez, *Thesis*, Bordeaux, 1911. (27) Ducelliez, *27*, **9**: 1017; 11. (28) Fawsitt, *54*, **25**: 1133; 06. (29) Fuchs, *93*, **109**: 80; 19. (30) Gerke, *1*, **44**: 1684; 22. (31) Gordon and Smith, *50*, **22**: 194; 18. (32) Haber and Sack, *9*, **8**: 245; 02. (33) Hainsworth, Rowley and MacInnes, *1*, **46**: 1437; 24. (34) Henderson, *2*, **29**: 507; 09. (35) Herschkowitsch, *7*, **27**: 123; 98. (36) van Heteren, *93*, **42**: 129; 04. (37) Heyn and Bauer, *93*, **52**: 129; 07. (38) Hulett and DeLury, *1*, **30**: 1805; 08. (39) Jones and Schumb, *65*, **56**: 199; 19. (40) Katayama, *7*, **61**: 560; 08. (41) Kremann and Battig, *95*, **12**: 414; 20. (42) Kremann and Eitel, *95*, **12**: 363; 21. (43) Kremann, Fritsch and Riebl, *95*, **13**: 66; 21. (44) Kremann and Gmachl-Pammer, *95*, **12**: 241; 20. (45) Kremann and Hofmeier, *57* **32**: 597; 11. (46, 47) Kremann and Knabel, *in B87*, **II, Pt. I**: 283, 391; 21. (48) Kremann and Langbauer, *93*, **127**: 239; 23. (49) Kremann, Langbauer and Rauch, *93*, **127**: 229; 23. (50) Kremann and Lobinger, *95*, **12**: 246; 20. (51) Kremann and Ruderer, *95*, **12**: 209; 20. (52) Kremann and Ruderer, *95*, **12**: 403; 20. (53) Kremann and Wittek, *95*, **13**: 90; 21. (54) Laurie, *3*, **33**: 94; 92. (55) Lewis and Argo, *1*, **37**: 1983; 15. (56) Lewis and Keyes, *1*, **34**: 119; 12. (57) Lewis and Keyes, *1*, **35**: 340; 13. (58) Lewis and Kraus, *1*, **32**: 1459; 10. (59) Mees, *Diss.*, Utrecht, 1916. (60) Muzaffar, *93*. **126**: 254; 23. (61) Nowak, *in B87*, **II, Pt. I**: 83; 21. (62) Palitsch, *186*, **1911**: 395. (63) Pélabon, *34*, **151**: 641; 10. (64) Pélabon, *34*, **154**: 1414; 12. (65) Pélabon, *14*, **13**: 121; 20. (66) Pushin, *53*, **34**: 856; 02. (67) Pushin, *93*, **36**: 201; 02. (68) Pushin, *53*, **39**: 13; 07. *93*, **56**: 1; 07. (69) Pushin, *53*, **39**: 528; 07. (70) Pushin, *53*, **39**: 869; 07. (71) Pushin and Lascenko, *53*, **41**: 23; 09. (72) Pushin and Lascenko, *93*, **62**: 34; 09. (73) Pushin and Pashskii, *53*, **40**: 826; 08. (74) Rathert, *9*, **20**: 145; 14. (75) Reinders, *93*, **25**: 126; 00. (76) Richards and Behr, *152*, **No. 61**; 06. (77) Richards and Behr, *7*, **58**: 301; 07. (78) Richards and Conant, *1*, **44**: 601; 22. (79) Richards and Daniels, *1*, **41**: 1732; 19. (80) Richards and Forbes, *152*, **No. 56**; 06. (81) Richards and Forbes, *7*, **58**: 301; 07. (82) Richards and Garrod-Thomas, *152*, **No. 118**; 09. (83) Richards and Garrod-Thomas, *7*, **72**: 165; 10. (84) Richards and Richards, *1*, **46**: 89; 24. (85) Richards and Smyth, *1*, **44**: 524; 22. (86) Richards and Wilson, *152*, **No. 118**; 09. (87) Richards and Wilson, *7*, **72**: 129; 10. (88) Saldau, *53*, **46**: 994; 14. (89) Sauerwald, *93*, **111**: 243; 20. (90) Schoeller, *9*, **5**: 259; 98. (90.5) Schreiner, *93*, **125**: 173; 23. (91) Shepherd, *50*, **7**: 15; 03. (92) Sichling, *7*, **77**: 1; 11. (93) Smith, *3*, **19**: 250; 10. (94) Smith and Gordon, *50*, **20**: 228; 16. (95) Tammann, *183*, **1917**: 345. (96) Tammann, *9*, **28**: 36; 22. (97) Taylor, *1*, **45**: 2865; 23. (98) Timofeev, *7*, **78**: 299; 11. (99) Timofeev, *7*. **86**: 113; 13. (100) Vigouroux, *27*, **7**: 191; 10. (101) Vigouroux and Bourbon, *27*, **9**: 873; 11. (102) Vigouroux, Ducelliez and Bourbon, *27*, **11**: 480; 12. (103) Walker and Dill, *78*, **11**: 153; 07.

THE EMF OF CONCENTRATION CELLS

H. S. Harned

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For the purpose of defining the scope of this section a concentration cell will be defined as one whose emf serves as a measure of the free energy change corresponding to a definite change in the activity of a molecular (or ionic) species *in the solution*.[1]

The section is divided into two parts as follows:

Part I. True concentration cells

These include all cells whose total emf is a direct measure of the free energy change. These are of two types as follows:

Type 1. Cells without transference

Example:

$$\left.\begin{matrix} H_2 \mid HCl(c_1) \mid AgCl \mid Ag \\ H_2 \mid HCl(c_2) \mid AgCl \mid Ag \end{matrix}\right\} \quad (1)$$

or by combining

$$Ag \mid AgCl \mid HCl(c_2) \mid H_2 \mid HCl(c_1) \mid AgCl \mid Ag \quad (2)$$

The cell reaction of cell (2) represents per faraday, the transfer of one equivalent of HCl from c_2 (activity a_2) to c_1 (activity a_1).

The equation for this cell is, $E = (RT/F) \log_e a_2/a_1$.

[1] For cells whose emf is a function of the activity of a molecular species *in the electrode*, *v.* p. 319.

Type 2. Cells with transference

Example:

$$H_2 \mid HCl(c_1) \mid HCl(c_2) \mid H_2$$

The equation for this type is, $E = (nRT/F) \log_e a_1/a_2$, where n is the number of equivalents transferred from activity a_1 to a_2 per faraday.

Part II. Cells with salt bridges

Each cell listed in this group is composed of one of the standard reference electrodes joined (usually by a salt bridge) to a half cell containing the ion-species whose activity is sought. If from the total emf of such a cell, the emf of the reference electrode plus the emf's at the liquid junctions be subtracted, the result is a measure of the activity of the given ion species under the conditions which prevail in the other half of the cell.

Since the correction for liquid junction potentials is in most cases a matter of considerable uncertainty in the present state of our knowledge, these cells are listed by literature reference only.

ABBREVIATIONS, SIGNS AND SYMBOLS

E_t	Emf in volts at t, °C.
mv	Millivolts.
|	Used to indicate a boundary between phases and to denote a liquid junction.
s, l, g	Solid, liquid, gas.
N	Gram-equivalents per liter.
c	Formula-weights per liter.
m	Formula-weights per kg of H_2O.
x	Wt. %.
satd.	Saturated solution.

LITERATURE

The older literature is not given except in cases where later and more accurate data are not available. For this older literature, *see* (1, 10).

I. TRUE CONCENTRATION CELLS

The positive end of the cell is marked +; negative values of E indicate a reversal of this polarity

Aqueous Solutions

A-B Table.—Standard arrangement (*v.* Vol. III, p. viii) in order of the molecular species whose concentration changes

Cl_2 (117); *cf.* (127, 177)

+Pt | $Cl_2(p)$, HCl(0.1N) | HgCl | Hg

p (atm.)	E_{25}	p (atm.)	E_{25}	p (atm.)	E_{25}
0.0490	1.0508	0.0249	1.0424	0.00629	1.0242
0.0492	1.0509	0.0243	1.0419	0.00631	1.0243
0.0495	1.0510	0.0124	1.0330	0.00298	1.0154
0.0247	1.0421	0.0125	1.0330	0.00293	1.0150

HCl

H_2 | HCl(m) | AgCl | Ag+

10^3m	$E_{25} \pm 0.0_32$	Lit.	10^3m	$E_{25} \pm 0.0_32$	10^3m	$E_{25} \pm 0.0_32$	Lit.
48.26	0.3874	(120)	4.83	0.5002	0.242	0.6514	(120)
9.65	.4658	(120)	1.00	0.5791	0.136	(0.6805)	(120)
10	.4665	(87)	0.483	0.6161			

(164)

m	E_{25}	m	E_{25}	m	E_{25}
0.01002	0.46376	0.09642	0.35393	0.5013	0.27195
0.01010	0.46331	0.09834	0.35316	0.6367	0.25902
0.01031	0.46228	0.2030	0.31774	0.9377	0.23696
0.04986	0.38582	0.3981	0.28407	1.0008	0.23290
0.05005	0.38568	0.5009	0.27197	1.5346	0.20534

(69)

m	E_{20}	m	E_{20}	m	E_{20}
0.01000	0.46303	0.10000	0.35315	0.5000	0.27419
0.02000	0.42968	0.20000	0.31998	0.7000	0.25611
0.05000	0.38602	0.3500	0.29244	1.0000	0.23564

(144)

m	E_{25}	m	E_{25}	m	E_{25}
0.0001182	0.6897	0.0006793	0.5987	0.004006	0.5094
0.0001529	0.6748	0.0008540	0.5870	0.007687	0.4768
0.0001602	0.6726	0.0008915	0.5849	0.01166	0.4565
0.0004185	0.6233	0.001376	0.5628	0.01970	0.4309
0.0004381	0.6210	0.001467	0.5597	0.02263	0.4242
0.0004579	0.6189	0.001705	0.5522	0.03616	0.4015
0.0005060	0.6137	0.001850	0.5480		
0.0005071	0.6137	0.003377	0.5178		

$E_t = E_{25}[1 + \alpha(t - 25) + \beta(t - 25)^2]$ (146)

m	E_{15}	E_{25}	E_{35}	$10^6\alpha$	$10^6\beta$
0.33314	0.29678	0.29348	0.28958	−1226.6	−10.22
0.09534	0.35600	0.35453	0.35270	− 465.4	− 5.08
0.03324	0.40530	0.40545	0.40513	− 20.97	− 5.80
0.00948	0.46452	0.46666	0.46824	398.6	− 6.00
0.003378	0.51325	0.51696	0.52023	675.0	− 4.26
0.000999	0.57308	0.57893	0.58421	960.7	− 4.81

H_2 | HCl(m) | HgCl | Hg+

$E_t = E_{25}[1 + \alpha(t - 25) + \beta(t - 25)^2]$ (51)

m	E_{18}	E_{25}	E_{35}	$10^6\alpha$	$10^6\beta$
4.484	0.15759	0.15506	0.15125	−2384	−7.82
1.9278	0.23769	0.23589	0.23304	−1137	−7.06
1.0381	0.27919	0.27802	0.27595	− 663	−8.23
0.7714	0.29654	0.29571	0.29411	− 460	−8.20
0.5095	0.31912	0.31865	0.31765	− 253	−6.00
0.3376	0.33845	0.33836	0.33794	− 75	−4.96
0.1004	0.39764	0.39884	0.40013	386	−6.47
0.03332	0.45020	0.45258	0.45557	715	−5.47
0.01001	(0.5271)	(0.5302)	(0.5369)	(1010)	(26.1)
0.003333		(0.8040)	(0.8105)		

m (119)	E_{25}	m (119)	E_{25}
0.01006	0.5109	6.75	0.0972
0.1009	0.39895	10.0	0.03025
1.029	0.2779	16.0	0.06625
2.25	0.2231		

Hg | HgCl | HCl(c) | H_2 | HCl(c = 1) | HgCl | Hg+ (31)

c	E_{25}	c	E_{25}	c	E_{25}
2	0.0490	6	0.1825	10	0.2940
3	0.0880	7	0.2138	11	0.3220
4	0.1190	8	0.2420	11.5	0.3360
5	0.1520	9	0.2630		

+Cl_2(1 atm.) | HCl(c) | H_2

Values of E_{30}(±0.006) from c = 5 to 12 (43, 139); *cf.* (117)

Ag | AgCl | HCl(c_1) | HCl(c_2) | AgCl | Ag+ (92)

c_1	c_2	E_{18}	c_1	c_2	E_{18}
0.03330	0.003329	0.09159	0.01665	0.001665	0.09232
0.01665	0.003329	0.06426	0.01113	0.001665	0.07662
0.01113	0.003329	0.04815	0.008315	0.001665	0.06485
0.008308	0.003329	0.03658	0.006686	0.001665	0.05612
0.006661	0.003329	0.02777	0.005561	0.001665	0.04882
0.03342	0.001665	0.11951			

Hg | HgCl | HCl(c_1) | HCl(c_2) | HgCl | Hg+ (37, 48); *cf.* (41, 57, 141, 163)

c_1	0.1	0.05	0.02	0.01	0.1
c_2	0.05	0.02	0.01	0.002	0.002
$E_{19.5}$	0.0272	0.0361	0.0278	0.0665	0.1596

+H_2 | HCl(c_1) | HCl(c_2) | H_2 (48)

c_1	0.1	0.1	0.1	0.05	0.02
c_2	0.05	0.02	0.01	0.02	0.01
E_{21}	0.00498	0.01138	0.01730	0.00685	0.00532

c_2 = 1 (31)

c_1	E_{25}	c_1	E_{25}	c_1	E_{25}
2	0.0082	6	0.0321	10	0.0666
3	0.0144	7	0.0395	11	0.0775
4	0.0195	8	0.0484	11.5	0.0836
5	0.0255	9	0.0571		

HCl.—(*Continued*)

H_2 | HCl, MCl_a | HgCl | Hg+

HCl	MCl_a	t	Lit.
c = 0.09 to 0.01	KCl, c = 0.01 to 0.09	25	(122)
m = 0.1 to 0.0_31	KCl, m = 0.0 to 0.1	25	(32)
c = 0.1	KCl, c = 0.0 to 3.0	25	(72)
m = 0.1004	KCl, m = 0.0 to 3.3	18	
m = 0.1004	NaCl, m = 0.1 to 3.7	25	(74)
m = 0.1004	LiCl, m = 0.4 to 4.5	30	
m = 0.01 to 0.1	LiCl, m = 0.4 to 4.0	25	(86)
m = 0.1	$BaCl_2$, m = 0.1 to 1.3	18	
m = 0.1	$SrCl_2$, m = 0.1 to 1.0	25	(80)
m = 0.1	$CaCl_2$, m = 0.1 to 1.0		
m = 0.01	KCl, m = 0.1 to 1.0	30	
m = 0.005 to 1.5	$BaCl_2$, m = 0.00625 to 0.9	25	(154)
m = 0.125 to 0.375	$LaCl_3$, m = 0.00417 to 0.125		
m = 0.001 to 3	KCl, m = 0.0 to 3; NaCl, m = 0.0 to 3; LiCl, m = 0.0 to 3	25	(79)

H_2 | HCl, MCl_a | AgCl | Ag+

HCl	MCl_a	t	Lit.
m = 0.01 to 0.1	KCl, m = 0.01 to 0.1; NaCl, m = 0.01 to 0.1; LiCl, m = 0.01 to 0.1; CsCl, m = 0.01 to 0.1	20	(69)

Ag | AgCl | HCl(c_1), HNO_3(c_2) | HNO_3(c_2), HCl(0.002c) | AgCl | Ag+

For c_1 = 0.01, 0.02, and 0.04 resp., c_2 = 0.005, 0.01, 0.02, and 0.04. 18° (157)

+H_2 | HCl(0.1m), gelatin(x%) | gelatin(x%), HCl(0.01m) | H_2 also Hg | HgCl | HCl(0.1m), gelatin(x%) | gelatin(x%), HCl (0.01m) | HgCl | Hg+

x = 0.0 to 20.0, 25° (57)

HBr

H_2 | HBr(m) | AgBr | Ag+

m	E_{25}	Lit.	m	E_{25}	Lit.	m	E_{25}	Lit.
0.01	0.3141	(118)	0.1086	0.1982	(121)	0.497	0.1214	(121)
0.03	0.2604	(118)	0.1878	0.1713	(121)	0.755	0.0980	(121)
0.085	0.2101	(121)	0.2400	0.1585	(121)	1.010	0.0804	(121)
0.1	0.2022	(118)	0.3075	0.1463	(121)	1.505	0.0535	(121)

H_2 | HBr, MBr_a | AgBr | Ag+

HBr	MBr_a	t	Lit.
m = 0.01 to 0.1	KBr, m = 0.0 to 3; NaBr, m = 0.0 to 3	25	(84)

+Pt | ½Br_2(c_1), HBr(c_2) | H_2 (15)

c_1	c_2	p_{H_2} (mm)	p_{Br_2} (mm)	p_{HBr} (mm)	E_{30}
0.049	11.5	742.5	0.682	12.0	0.573
0.125	10.2	753.6	1.509	2.25	0.625
0.127	8.7	760.6	1.448	1.119	0.636

H_2 | HBr(c_1) | HBr(c_2) | H_2+ (133)

Hg | HgBr | HBr(0.126c) | HBr(0.0132c) | HgBr | Hg+

E_{18} = 0.0932 (141)

I_2

+[Pt] | I_2(c_1), HI(c_2) | HI(c_2) | H_2 (176)

c_1	c_2	$E_{31.6}$	$E_{55.2}$	$E_{81.6}$
0.335	4.62	0.3028	0.2789	0.2466
0.29	5.8	0.2372	0.2126	0.1819
0.595	5.8	0.2448	0.2228	0.1918

[Pt] | I_2(c_1), KI(c_2) | KI(c_2), I_2(c_3) | [Pt]+ (107)

c_1	c_2	c_3	$E_{20.4}$	c_1	c_2	c_3	$E_{20.4}$
0.05	0.115	0.005	0.0444	0.0322	1.0	0.0139	0.0108
0.005	0.115	0.0005	0.0304	0.056	1.0	0.0139	0.0184
0.05	0.23	0.005	0.0352	0.109	1.0	0.0139	0.0273
0.005	0.23	0.0005	0.0297	0.209	1.0	0.0139	0.0376
0.05	0.344	0.005	0.0326	0.279	1.0	0.0139	0.0434
0.005	0.344	0.0005	0.0295	0.362	1.0	0.0139	0.0491
				0.508	1.0	0.0139	0.0588

+I_2(s) | KI(c_1) | KI(c_1), I_2(0.0_35c) | [Pt] (108)

c_1	E_{25}	c_1	E_{25}
0.025	0.0640	0.5	0.1040
0.05	0.0728	0.7	0.1099
0.115	0.0830	0.85	0.1136
0.344	0.0987	1.0	0.1172

+I_2(s) | KI(c_1) | NH_4NO_3(10c) | KI(c_1), I_2(0.0_35c) | [Pt] (108)

c_1	E_{25}	c_1	E_{25}
0.025	0.0670	0.5	0.1086
0.05	0.0762	0.7	0.1154
0.115	0.0869	0.85	0.1200
0.344	0.1031	1.0	0.1252

HI

H_2 | HI(m) | AgI | Ag+ (150)

m	E_{25}	E_{30}	E_{35}
0.00505	0.12417	0.12707	0.12964
0.01045	0.08825	0.09060	0.09262
0.01981	0.05735	0.05931	0.06083
0.05049	0.00106	0.01128	0.01235
0.07914	−0.01210	−0.01128	−0.01073
0.1297	−0.03615	−0.03556	−0.03531
0.2461	−0.06905	−0.06864	−0.06829

H_2SO_4

H_2 | H_2SO_4(m) | Hg_2SO_4 | Hg+ (155)

m	E_{25} ± <0.0_32	m	E_{25} ± <0.0_32
0.005	0.8160	2.313	0.6442
0.05	0.7546	2.922	0.6315
0.1112	0.7343	3.859	0.6145
0.2789	0.7114	4.827	0.5975
0.5607	0.6929	6.168	0.5770
0.8453	0.6812	8.295	0.5495
1.133	0.6720	13.88	0.4985
1.717	0.6571		

H_2 | H_2SO_4(c) | Hg_2SO_4 | Hg+ (28)

c = 0.00482		c = 0.01506		c = 0.0673	
t	E	t	E	t	E
15.7	0.8240	15.7	0.7925	13.7	0.7494
25.7	0.8243	25.7	0.7927	25.2	0.7493
37.8	0.8246	37.8	0.7930	35.7	0.7491
49.5	0.8249	49.5	0.7933	47.8	0.7485
64.1	0.8259	64.1	0.7939	59.9	0.7486
79.9	0.8263	79.9	0.7949	82.1	0.7527

c = 0.2784		c = 1.235		c = 4.837	
t	E	t	E	t	E
13.7	0.7155	13.9	0.6402	15.6	0.6012
25.2	0.7144	25.7	0.6371	26.1	0.5986
35.7	0.7132	37.4	0.6333	37.0	0.5957
47.8	0.7116	49.4	0.6295	48.7	0.5925

H_2SO_4.—(*Continued*)

c = 0.2784		c = 1.235		c = 4.837	
t	E	t	E	t	E
59.9	0.7104	60.5	0.6267	60.8	0.5892
82.1	0.7132	70.9	0.6240	73.8	0.5857
		80.2	0.6207		

c = 0.1110		c = 14.87	
t	E	t	E
15.6	0.5698	16.6	0.4995
26.1	0.5673	28.4	0.4970
37.0	0.5646	40.8	0.4943
48.7	0.5617	55.6	0.4906
60.8	0.5582	70.2	0.4864
73.8	0.5542		

$+H_2 \mid H_2SO_4(c) \mid PbSO_4 \mid Pb$ (44)

c	0.513	1.01	2.30	3.20	7.70
E_0	0.269	0.282	0.317	0.339	0.426

$H_2 \mid H_2SO_4(c) \mid PbSO_4 \mid PbO_2+$ (44)

c	0.513	1.01	2.30	3.20	7.70
E_0	1.610	1.617	1.654	1.682	1.801

$+PbO_2 \mid PbSO_4 \mid H_2SO_4(c) \mid PbSO_4 \mid Pb$

c	1.000	0.360	0.180	0.111	0.0505	0.0124	0.00046	(44)
E_0	1.896	1.841	1.808	1.782	1.745	1.672	1.472	

c	E_{25}	c	E_{25}	c	E_{25}
0.077	1.744	1.16	1.929	3.89	2.067
0.200	1.815	1.66	1.958	4.67	2.094
0.658	1.892	2.60	2.004	6.97	2.198
0.891	1.911	2.99	2.029	(97)	

$+Pb \mid PbSO_4 \mid H_2SO_4(c_1) \mid H_2SO_4(c_2) \mid PbSO_4 \mid Pb$
c_2 = 2.99 (97)

c_1	E_{25}	c_1	E_{25}
0.077	0.1033	2.39	0.0115
0.200	0.0762	2.63	0.0038
0.658	0.0507	4.14	−0.0157
1.66	0.0248	4.67	−0.0179

c_1	c_2	E_{17}	c_1	c_2	E_{17}
3.0	1.5	0.0315	0.188	0.094	0.016
1.5	0.75	0.021	0.375	0.094	0.0308
0.75	0.375	0.017	0.75	0.094	0.0462
0.375	0.188	0.015		(140)	

$+H_2 \mid H_2SO_4(0.1m) \mid H_2SO_4(0.01m) \mid H_2$
E_{25} = 0.01131 (53)

$H_2 \mid H_2SO_4(c) \mid H_2SO_4(c = 3) \mid H_2+$ (97)

c	E_{17}	c	E_{17}
0.046	−0.0252	7.19	0.0281
0.184	−0.0179	10.0	0.0557
0.364	−0.0149	11.07	0.0686
1.49	−0.0058	12.37	0.0928
4.50	0.0082	13.17	0.1192

$Hg \mid Hg_2SO_4 \mid H_2SO_4(0.1m) \mid H_2SO_4(0.01m) \mid Hg_2SO_4 \mid Hg+$
E_{25} = 0.04925 (54)

$H_2 \mid H_2SO_4, M_xSO_4 \mid Hg_2SO_4 \mid Hg+$

H_2SO_4	M_xSO_4	t	Lit.
m = 0.1 and 0.01	K_2SO_4, m = 0.0 to 0.5 Na_2SO_4, m = 0.0 to 1 $MgSO_4$, m = 0.0 to 1	25	(85)
m = 0.05 and 0.005	K_2SO_4, c = 0.0 to 0.625 Na_2SO_4, c = 0.0 to 2 Li_2SO_4, c = 0.0 to 2	25	(7)
m = 0.05 to 2	Na_2SO_4, m = 0.05 to 2	25	(156)

NH_3

v. CuOH, $Zn(OH)_2$, $AgNO_3$, $Cd(OH)_2$ and AgCl

NH_4Cl

$Hg \mid HgCl \mid NH_4Cl(0.1N) \mid NH_4Cl(0.01N) \mid HgCl \mid Hg+$
E_{18} = 0.0546 (141)

$(C_6H_5CH_2)_3(CH_3)NCl$, Tribenzylmethylammonium bromide (T)
$Ag \mid AgBr \mid TBr(c_1) \mid TBr(c_2) \mid TBr(c_2) \mid AgBr \mid Ag+$
Also the same cell with salt bridges (45)

$PbCl_2$

$Pb_xHg \mid PbCl_2(c) \mid AgCl \mid Ag+$ (27)

t, °C \ c	satd.	0.0265	0.00984
0	0.4864	0.4831	0.5092
16.7	0.4801	0.4859	0.5128
30.5	0.4747	0.4875	0.5153
40.5	0.4707	0.4884	0.5168
49.3	0.4672	0.4888	0.5177
58.3	0.4637	0.4888	0.5183
67.0	0.4601	0.4886	0.5186
76.0	0.4560	0.4882	0.5187
84.0	0.4529	0.4878	0.5184
92.2	0.4497	0.4868	0.5177

$Pb(NO_3)_2$

$+Pb_xHg \mid Pb(NO_3)_2(c_1) \mid Pb(NO_3)_2(c_2) \mid Pb_xHg$

c_1	0.5	0.05	0.005	0.5	(37)
c_2	0.05	0.005	0.0005	0.0005	
E_{room}	0.026	0.035	0.043	0.104	

$+Pb \mid Pb(NO_3)_2(c_1) \mid Pb(NO_3)_2(c_2) \mid Pb$

c_1	c_2	E_{room}	Lit.
0.5	0.05	0.030	(105)
0.05	0.005	0.040	

$Pb(C_2H_3O_2)_2$

$+Pb \mid PbAc_2(c_1) \mid PbAc_2(c_2) \mid Pb$

c_1	c_2	E_{room}	Lit.
0.5	0.05	0.010	(105)
0.05	0.005	0.015	

$Zn(OH)_2$

$Zn \mid ZnO(c_1), NaOH(c_2) \mid ZnO(c_1) \mid NaOH(c_3) \mid Zn+$
c_1 = 0.012 to 0.0024; c_2 = 0.37 to 1.95; c_3 = 0.09 to 0.97; room temp. (104)

$Zn \mid Zn(OH)_2(c_1), NH_3(c_2) \mid Zn(OH)_2(c_1), NH_3(c_3) \mid Zn$
c_1 = 0.125 to 0.00825; c_2 = 3, 4, 5 and 6; c_3 = 1.5, 2 and 4; 25° (22)

$ZnCl_2$

Zn | $ZnCl_2(m$ and $c)$ | AgCl | Ag+

m	E_{25}	m	E_{25}	c	E_{25}
(87)		(87)		(91)	
0.01021	1.1558	0.001253	1.2289	0.566	1.0306
0.006022	1.1742	0.000772	1.2475	1.112	1.0171
0.003112	1.1953	0.000649	1.2497	2.22	0.9740
0.001453	1.2219	0.0003995	1.2699		
		0.0003478	1.2701		

$Zn_{1\%}Hg$ | $ZnCl_2(c)$ | HgCl | Hg+ (110)

c	$E_{20.2}$	c	$E_{20.2}$
9.97	0.8539	0.550	1.0626
6.76	0.9245	0.454	1.0683
6.16	0.9385	0.385	1.0755
4.54	0.9740	0.275	1.0851
3.08	1.0005	0.137	1.1081
1.54	1.0300	0.077	1.1269
1.10	1.0406	0.068	1.1309
0.77	1.0528	0.0616	1.1298
0.616	1.0573	0.034	1.1524

Zn_xHg | $ZnCl_2(c_1)$ | HgCl | Hg | HgCl | $ZnCl_2(c_2)$ | Zn_xHg
Also same with AgCl | Ag | AgCl bridge (66)

Zn | $ZnCl_2(m)$ | $Cl_2(p)$ | Pt (56)
t = 60.5 and 80.4°C; m = 0.07 to 25; p = 1 atm.

+Zn | $ZnCl_2(2.35c)$ | $ZnCl_2(0.144c)$ | Zn
E_{25} = 0.0751 (30)

Zn | $ZnCl_2(m_1)$ | $ZnCl_2(m_2)$ | Zn (56)
t = 60.5 and 80.4°C; m_1 = 2.4 to 25; m_2 = 0.87 to 4.85

Pt | $Cl_2(p)$ | $ZnCl_2(m_1)$ | $ZnCl_2(m_2)$ | $Cl_2(p)$ | Pt (56)
t = 60.5 and 80.4°C; m_1 = 2.4 to 25; m_2 = 0.87 to 4.85; p = 1 atm.

$ZnBr_2$

Zn_xHg | $ZnBr_2(c_1)$ | HgBr | Hg | HgBr | $ZnBr_2(c_2)$ | Zn_xHg
Also same cell with AgBr | Ag | AgBr bridge (67)

$ZnSO_4$

Zn-Hg(2-phase) | $ZnSO_4(m)$ | $PbSO_4$ | Pb-Hg(2-phase) + (24)

m	E_{25}	m	E_{25}	m	E_{25}
0.000658	0.6074	0.00506	0.5658	0.2532	0.5077
0.000670	0.6072	0.00910	0.5552	0.3518	0.5037
0.000687	0.6067	0.01712	0.5449	0.8564	0.4932
0.000702	0.6060	0.01824	0.5439	1.426	0.4858
0.001505	0.5898	0.04120	0.5317	2.052	0.4783
0.001648	0.5878	0.08532	0.5211	2.749	0.4685
0.003322	0.5737	0.1732	0.5122	3.419	0.4581

$Zn_{1\%}Hg$ | $ZnSO_4(c)$ | Hg_2SO_4 | Hg+

c	2.6	1.5	1.0	0.87	(110)
$E_{20.2}$	1.4306	1.4452	1.4520	1.4545	

Zn_xHg | $ZnSO_4(c_1)$ | $PbSO_4$ | Pb_xHg | $PbSO_4$ | $ZnSO_4(c_2)$ | Zn_xHg+

c_1	0.1	0.05	0.01	(66)
c_2	0.01	0.005	0.001	
E_{25}	0.0427	0.0441	0.0522	

+Zn | $ZnSO_4(c_1)$ | $ZnSO_4(c_2)$ | Zn

c_1	1.10	1.10	1.10	0.554	(30)
c_2	0.554	0.277	0.139	0.139	
E_{25}	0.0062	0.0116	0.0171	0.0101	

+Zn_xHg | $ZnSO_4.7H_2O$ | $ZnSO_4$(satd.) | $ZnSO_4(c)$ | Zn_xHg

t	c	E	Lit.
15	1.198	0.02045	(33)
25	1.371	0.02444	

Hg | Hg_2SO_4 | $ZnSO_4.7H_2O$ | $ZnSO_4$(satd.) | $ZnSO_4(c)$ | Hg_2SO_4 | Hg+

t	c	E	Lit.
15	1.198	0.0057	(33)
25	1.371	0.00648	

ZnC_2O_4

Zn | $ZnC_2O_4(c_1)$, $K_2C_2O_4(c_2)$ | $K_2C_2O_4(c_3)$, $ZnC_2O_4(c_4)$ | Zn
c_1 = 0.004 to 0.014; c_2 = 0.125, 0.25 and 0.5; c_3 = 0.0625 to 0.25; c_4 = 0.0019 to 0.0144; room temp. (104)

$Cd(OH)_2$

Cd | $Cd(OH)_2(c_1)$, $NH_3(c_2)$ | $NH_3(c_3)$, $Cd(OH)_2(c_1)$ | Cd
c_1 = 0.0042 and 0.00835; c_2 = 5 and 6.45; c_3 = 2, 3.2, 3 and 4; 25° (22)

$CdCl_2$

$Cd_{4.6\%}Hg$ | $CdCl_2(m)$ | AgCl | Ag+

m	$E_{25} \pm 1$ mv	m . . .	$E_{25} \pm 1$ mv
6.62	0.62203	0.0003363	0.8644
0.0995	0.6996	0.0002144	0.8803
0.0074	0.76305	0.0001527	0.8926
0.003519	0.7864	0.0001269	0.8978
0.002581	0.7958	0.0001137	0.9011
0.000924	0.8296	0.0001087	0.9023
0.000479	0.852	0.0001029	0.9060
0.0003659	0.8614	(87)	

Cd | $CdCl_2(c)$ | AgCl | Ag+ (13)

c	E_{20}	c	E_{20}
0.493	0.7239	2.229	0.6995
0.525	0.7225	3.247	0.6915
0.651	0.7191	4.404	0.6834
1.006	0.7123	5.775	0.6743

Cd | $CdCl_2(m)$ | HgCl | Hg+ (63)

m	E_{25}	m	E_{25}	m	E_{25}
0.00086	0.9155	0.0311	0.8198	5.035	0.7311
0.0031	0.8667	0.0622	0.8063	5.454	0.7302
0.0062	0.8727	0.0819	0.8014	5.909	0.7286
0.0086	0.8485	0.1556	0.7866	6.591	0.7182
0.0164	0.8325	0.3113	0.7752		

+Cd | $CdCl_2(c_1)$ | $CdCl_2(c_2)$ | Cd (12)

c_1	c_2	E_{20}	c_1	c_2	E_{20}
1.097	0.4932	0.0083	3.394	0.3399	0.0287
1.580	0.5403	0.0113	2.464	0.2486	0.0259
2.062	0.4923	0.0160	2.052	0.2100	0.0244
2.552	0.5058	0.0191	1.596	0.1623	0.0244
3.444	0.4963	0.0252	1.062	0.1089	0.0244
4.144	0.4942	0.0309	0.4818	0.04822	0.0264
4.798	0.4871	0.0353	0.2080	0.02214	0.0275
4.096	0.4145	0.0318	0.0492	0.00563	0.0317

Ag | AgCl | $CdCl_2(c)$ | $CdCl_2(0.5c)$ | AgCl | Ag+

c	E_{20}	c	E_{20}
0.697	0.00202	3.251	0.00822
0.880	0.00327	4.667	0.00782
1.136	0.00462	5.59	0.00642
1.653	0.00623	5.83	0.00588
2.426	0.00782	(13)	

$CdBr_2$

Cd | $CdBr_2(m)$ | HgBr | Hg+ [63]

m	E_{25}	m	E_{25}	m	E_{25}
0.0012	0.7624	0.0476	0.6915	0.4756	0.6452
0.0029	0.7507	0.0732	0.6805	3.159	0.6051
0.0048	0.7368	0.1172	0.6733	4.192	0.6000
0.0117	0.7202	0.1877	0.6640		
0.0293	0.6993	0.2929	0.6551		

$CdSO_4$

Cd | $CdSO_4(m)$ | Hg_2SO_4 | Hg+ [63]

m	E_{25}	m	E_{25}	m	E_{25}
0.0014	1.1438	0.1328	1.1178	1.386	1.0926
0.0055	1.1484	0.1386	1.1152	2.125	1.0809
0.0139	1.1399	0.2217	1.1130	2.656	1.0768
0.0554	1.1285	0.5542	1.1033	3.698	1.0656

+Cd | $CdSO_4(0.5c)$ | Hg_2SO_4 | Hg | Hg_2SO_4 | $CdSO_4(0.05c)$ | Cd

E_{25} = 0.020 [105]

+Cd | $CdSO_4(c_1)$ | $CdSO_4(c_2)$ | Cd

c_1	1.09	1.09	0.541	[30]
c_2	0.277	0.139	0.139	
E_{25}	0.0108	0.0164	0.0099	

$Hg_2(NO_3)_2$

Hg | $Hg_2(NO_3)_2(c_1)$, $HNO_3(0.1N)$ | $HNO_3(0.1N)$, $Hg_2(NO_3)_2(c_2)$ | Hg+

c_1	0.1	0.05	0.005	0.0005	[147]
c_2	0.01	0.005	0.0005	0.00005	
E_{18}	0.0266	0.0274	0.0290	0.0304	

CuOH

Cu | $CuOH(c_1)$, $NH_3(c_2)$ | $NH_3(c_3)$, $CuOH(c_4)$ | Cu

c_1 = 0.0001 to 0.002; c_2 = 0.37 to 1.76; c_3 = 0.5 and 0.37; c_4 = 0.0002 to 0.001; room temp. [16]

CuCl

Cu | $CuCl(c_1)$, $KCl(c_2)$ | $KCl(c_3)$, $CuCl(c_4)$ | Cu

$c_1 = 0.0_47$ to 0.05; c_2 = 0.1 to 2.0; c_3 = 0.05 to 1.0; $c_4 = 0.0_47$ to 0.05; room temp. [20, 21]

CuBr, analogue of CuCl above [21]

$CuSO_4$

Hg | Hg_2SO_4 | $CuSO_4(m_1)$ | Cu_xHg | $CuSO_4(m_2)$ | Hg_2SO_4 | Hg+

m_1	0.1	0.5	0.5	[143]
m_2	0.05	0.2	0.1	
E_{25}	0.0089	0.0105	0.0190	

Cu | $CuSO_4(m)$ | Hg_2SO_4 | Hg+

E (±0.00023) = 0.3928 for m = 0.05; = 0.4226 for m = 0.005 [115]; *cf.* [132]

+Cu | $CuSO_4(c_1)$ | $CuSO_4(c_2)$ | Cu

c_1	0.01	0.921	0.5	0.05
c_2	0.001	0.277	0.05	0.005
E_{25}	0.0299	0.0098	0.022 (room)	
Lit	[61]	[30]	[105]	[105]

$Cu(NO_3)_2$

Cu | $Cu(NO_3)_2(c_1)$ | $Cu(NO_3)_2(10c_1)$ | Cu+

E = 0.048 for c_1 = 0.05; = 0.040 for c_1 = 0.005; room temp. [105]

AgCl

Ag | $AgCl(c_1)$, $NH_3(c_2)$ | $NH_3(c_3)$, $AgCl(c_4)$ | Ag

$c_1 = 0.0_34$ to 0.05; c_2 = 0.1 to 7.5; c_3 = 0.1 to 5.0; $c_4 = 0.0_44$ to 0.05; 17–18° [19]

AgI

Ag | $AgI(c_1)$, $KI(c_2)$ | $KI(c_3)$, $AgI(c_4)$ | Ag

$c_1 = 0.0_32$ to 0.01; c_2 = 0.33 to 2.0; c_3 = 0.17 to 2.0; $c_4 = 0.0_316$ to 0.005; room temp. [18]

$AgNO_2$

+Ag | $AgNO_2$(satd.) | $AgNO_2(0.0244c)$ | Ag

E = 0.011 [3]

$AgNO_3$

+Ag | $AgNO_3(c_1)$ | $AgNO_3(c_2)$ | Ag

c_1	c_2	E_{25}	c_1	c_2	E_{25}
[11]			[40, 41]		
1.0	0.1	0.0472	0.5	0.1	0.0312
1.0	0.01	0.1036	0.1	0.01	0.0590
0.3	0.03	0.0536	0.01	0.001	0.0618
0.3	0.003	0.1138			
0.1	0.01	0.0566			
0.03	0.003	0.0601			
0.01	0.001	0.0602			

+ Ag | $AgNO_3(c_1)$ | $NH_4NO_3(10c)$ | $AgNO_3(c_2)$ | Ag

$c_1 \rightarrow c_2$	0.5→0.1	0.1→0.01	0.01→0.001	[40, 41]
E_{25}	0.0286	0.0556	0.0579	

+ Ag | $AgNO_3(c_1)$ | KNO_3(satd.) | $AgNO_3(c_2)$ | Ag

$c_1 \rightarrow c_2$	0.5→0.1	0.1→0.01	[40, 41]
E_{25}	0.0290	0.0555	

Ag | $AgNO_3(c_1)$, $NH_3(c_2)$ | $NH_3(c_3)$, $AgNO_3(c_4)$ | Ag

$c_1 = 0.0_34$ to 0.05; c_2 = 0.1 to 7.5; c_3 = 0.1 to 2.5; $c_4 = 0.0_44$ to 0.05; room temp. [19]

+Ag | $AgNO_3(c_1)$, $KNO_3(2c)$ | $KNO_3(2c)$, $AgNO_3(c_2)$ | Ag

c_1	0.20	0.10	0.05	0.025	[29]
c_2	0.10	0.05	0.025	0.0125	
E_{20}	0.01781	0.01762	0.01783	0.01749	

AgCN; *v.* $KAg(CN)_2$

AgCNS

Ag | $AgCNS(c_1)$, $KCNS(c_2)$ | $KCNS(c_3)$, $AgCNS(c_4)$ | Ag

$c_1 = 0.0_32$ to 0.1; c_2 and c_3 = 0.1 to 2.0; $c_4 = 0.0_325$ to 0.025; room temp. [17, 18]

$MgCl_2$

Hg | HgCl | $MgCl_2(c_1)$ | $MgCl_2(c_2)$ | HgCl | Hg+ [59]

c_1	c_2	E_{18}	c_1	c_2	E_{18}
2.0	1.75	0.0019	0.5	0.1	0.0199
1.75	1.5	0.0025	0.1	0.01	0.0290
1.5	1.0	0.0057	0.01	0.001	0.0346
1.0	0.5	0.0104	0.001	0.0001	0.0358

Ag | AgCl | $MgCl_2(c_1)$, $MgSO_4(2N)$ | $MgSO_4(2N)$, $MgCl_2(c_2)$ | AgCl | Ag+

10^3c_1	200.05	20.05	2.049	[29]
10^3c_2	20.05	2.049	0.250	
E_{20}	0.0562	0.0573	0.0524	

$CaCl_2$

Ag | AgCl | $CaCl_2(m)$ | Ca_xHg | $CaCl_2(0.01m)$ | AgCl | Ag+ [124]

m	E_{25}	m	E_{25}	m	E_{25}
0.0350	0.0411	0.4655	0.1335	1.606	0.2105
0.0629	0.0606	0.6622	0.1543	1.960	0.2313
0.1032	0.0772	0.9608	0.1750	3.167	0.2856
0.2066	0.1014	1.003	0.1773	3.502	0.3005
0.3713	0.1235				

$CaCl_2$.—(*Continued*)

Ag | AgCl | $CaCl_2(m)$ | $CaCl_2(0.01m)$ | AgCl | Ag+ (124)

m	E_{25}	m	E_{25}	m	E_{25}
0.0155	0.0060	0.0805	0.0284	1.013	0.0626
0.0201	0.0097	0.1612	0.0368	1.600	0.0716
0.0395	0.0190	0.3208	0.0460	2.586	0.0836
0.0497	0.0220	0.6162	0.0549		

$SrCl_2$

Ag | AgCl | $SrCl_2(m)$ | Sr_xHg | $SrCl_2(0.01m)$ | AgCl | Ag+ (124)

m	E_{25}	m	E_{25}	m	E_{25}
0.0291	0.0352	0.3458	0.1170	2.115	0.2030
0.0900	0.0722	1.049	0.1612	3.015	0.2356
0.1167	0.0798	1.403	0.1767		

Ag | AgCl | $SrCl_2(m)$ | $SrCl_2(0.01m)$ | AgCl | Ag+ (124)

m	E_{25}	m	E_{25}	m	E_{25}
0.0158	0.0064	0.1466	0.0356	2.027	0.0721
0.0320	0.0157	0.3168	0.0453	2.954	0.0818
0.0456	0.0208	0.6246	0.0540		
0.0792	0.0277	1.269	0.0642		

$BaCl_2$

Ag | AgCl | $BaCl_2(m)$ | Ba_xHg | $BaCl_2(m_0)$ | AgCl | Ag+ $m_0 = 0.01$ (124)

m	E_{25}	m	E_{25}	m	E_{25}
0.0302	0.0355	0.2978	0.1092	1.521	0.1718
0.1004	0.0742	0.9710	0.1532	1.650	0.1771

(151)

m_0	m	E_{25}	m_0	m	E_{25}
0.003	0.03	0.0756	0.01	0.1	0.0744
0.005	0.05	0.0753	0.03	0.3	0.0739
0.003	0.1	0.1142	0.1	1	0.0766
0.005	0.1	0.0965	0.3	1.256	0.0686

Ag | AgCl, $BaCl_2(m)$ | $BaCl_2(m_0)$ | AgCl | Ag+ $m_0 = 0.01$; 25° (124)

m	E_{25}	m	E_{25}	m	E_{25}
0.0192	0.00927	0.2426	0.0428	0.8122	0.0599
0.0381	0.0185	0.3927	0.0491	1.372	0.0687
0.0798	0.0280	0.5971	0.0547	1.715	0.0713
0.1719	0.0394				

(151)

m_0	m	E_{25}	m_0	m	E_{25}
0.003	0.030	0.0344	0.03	0.3	0.0310
0.005	0.050	0.0337	0.1	1	0.0312
0.010	0.100	0.0321			

+Hg | HgCl | $BaCl_2(c_1)$ | $BaCl_2(c_2)$ | HgCl | Hg (46)

c_1	E_{20}, c_2 = 0.1	E_{20}, c_2 = 0.05	E_{20}, c_2 = 0.02	E_{20}, c_2 = 0.01	E_{20}, c_2 = 0.005
0.05	0.0095				
0.02	0.0209	0.0117			
0.01	0.0324	0.0229	0.0091		
0.005	0.0436	0.0355	0.0209	0.0107	
0.002	0.0613	0.0475	0.0350	0.0233	0.0150
0.001	0.0716	0.0578	0.0706	0.0356	0.0248

+$Ba_{1\%}Hg$ | $BaCl_2(c_1)$ | KCl(2N) | $BaCl_2(0.005c)$ | $Ba_1\%Hg$

c_1	0.01	0.02	0.0505	0.103	(46)
E	0.0071	0.0147	0.0263	0.0342	

Ag | AgCl | $BaCl_2(0.5c)$ | Ba_xHg | $BaCl_2(0.1N)$, sucrose(y) | AgCl | Ag+

x = 0.1 and 0.01 %, y = 40 % and 60 % by vol. of solution; 25° (38)

$BaBr_2$

(A) Ag | AgBr | $BaBr_2(m)$ | Ba_xHg | $BaBr_2(m_0)$ | AgBr | Ag+
(B) Ag | AgBr | $BaBr_2(m)$ | $BaBr_2(m_0)$ | AgBr | Ag+ (60)

m_0	m	(A) E_{25}	(B) E_{25}
0.003	0.03	0.0774	0.0339
0.005	0.05	0.0764	0.0332
0.010	0.050	0.0527	0.0227
0.010	0.100	0.0744	0.0322
0.030	0.100	0.0390	0.0164
0.030	0.300	0.0759	0.0313
0.050	0.500	0.0782	0.0314
0.100	1.000	0.0822	0.0319

+Hg | HgBr | $BaBr_2(c_1)$ | $BaBr_2(c_2)$ | HgBr | Hg (46)

c_1	E_{20}, c_2 = 0.1	E_{20}, c_2 = 0.05	E_{20}, c_2 = 0.02	E_{20}, c_2 = 0.01	E_{20}, c_2 = 0.005	E_{20}, c_2 = 0.002
0.05	0.0095					
0.02	0.0238	0.0133				
0.01	0.0325	0.0220	0.0104			
0.005	0.0414	0.0340	0.0213	0.0093		
0.002	0.0582	0.0486	0.0342	0.0233	0.0120	
0.001	0.0707	0.0627	0.0509	0.0398	0.0272	0.0126

+$Ba_{1\%}Hg$ | $BaBr_2(c)$ | KCl(2N) | $BaBr_2(0.01N)$ | $Ba_{1\%}Hg$

c	0.0201	0.0505	0.103	(46)
E_{20}	0.0084	0.0169	0.0259	

LiOH

H_2 | LiOH(m) | Li_xHg | LiOH(m_0) | H_2 + (86)

m	m_0	E_{25}	m	m_0	E_{25}
0.0505	0.0101	0.0761	0.553	0.1006	0.0765
0.1008	0.0101	0.1088	0.611	0.1011	0.0808
0.1038	0.0103	0.1084	1.063	0.1006	0.1069
0.0978	0.0235	0.0669	1.812	0.0997	0.1307
0.242	0.1013	0.0396	2.386	0.1043	0.1412
0.346	0.0993	0.0566	2.577	0.1051	0.1438
0.432	0.0993	0.0664	3.926	0.1051	0.1651

H_2 | LiOH, LiCl | Li_xHg | LiOH | H_2 +

LiOH	LiCl	t	Lit.
m = 0.01	m = 0.0 to 8.36	25	(86)
m = 0.1	m = 0.0 to 8.48	25	(86)

LiCl

Ag | AgCl | $LiCl(m_1)$ | Li_xHg | $LiCl(m_2)$ | AgCl | Ag +

m_1	m_2	E_{25}	m_1	m_2	E_{25}
3.0	0.3	0.14170	0.1	0.01	0.11055
1.0	0.1	0.11650	0.03	0.003	0.11275
0.3	0.1	0.05370	0.01	0.001	0.1139
0.3	0.03	0.11117		(130)	

Ag | AgCl | $LiCl(m_1)$ | $LiCl(m_2)$ | AgCl | Ag +

m_1	m_2	E_{25}	m_1	m_2	E_{25}
3.0	0.3	0.03957	0.1	0.01	0.03589
1.0	0.1	0.03543	0.03	0.003	0.03560
0.3	0.1	0.01642	0.01	0.001	0.03906
0.3	0.03	0.03521		(130)	

LiCl.—(*Continued*)

Ag | AgCl | LiCl(c_1), $LiNO_3$(c_2) | $LiNO_3$(c_2), LiCl(0.002c) | AgCl | Ag +

Values of E_{18} (157)

c_1 \ c_2	0.005	0.01	0.02	0.04
0.01	0.0341	0.0362	0.0371	0.0368
0.02	0.0466	0.0510	0.0533	0.0531
0.04	0.0584	0.0628	0.0656	0.0682

Li_2SO_4

Hg | Hg_2SO_4 | Li_2SO_4(m) | Li_xHg | Li_2SO_4(0.05m) | Hg_2SO_4 | Hg + (7)

m	E_{25}	m	E_{25}	m	E_{25}
0.025	−0.0205	0.495	0.0684	1.447	0.1041
0.125	0.0274	0.979	0.0890	1.903	0.1143
0.249	0.0481				

NaOH

H_2 | NaOH(m) | Na_xHg | NaOH(m_0) | H_2 + (75)

m	m_0	E_{25}	m	m_0	E_{25}
0.01011	0.00530	0.0315	0.3975	0.00995	0.1762
0.0202	0.01001	0.0338	0.807	0.01006	0.2103
0.0526	0.01000	0.0795	1.020	0.01016	0.2221
0.1047	0.00998	0.1116	1.517	0.01003	0.2459
0.1081	0.00984	0.1142	2.024	0.01014	0.2630
0.1934	0.00997	0.1416	3.100	0.01012	0.2926

H_2 | NaOH, NaX | Na_xHg | NaOH | H_2 +

NaOH	NaX	t	Lit.
m = 0.01 and 0.1	NaCl, m = 0 to 3.1	25	(76)
m = 0.1	NaBr, m = 0 to 3.1	25	(84)

H_2 | NaOH, Na_2SO_4 | Na_xHg | NaOH | H_2 +

NaOH	Na_2SO_4	t	Lit.
m = 0.01 and 0.1	c = 0.0 to 2.5	25	(7)

Hg | HgO | NaOH(0.235c) | NaOH(0.03c) | HgO | Hg +
E_{18} = 0.0178 (141)

NaCl

$Na_{0.139\,\%}Hg$ | NaCl(c) | HgCl | Hg+ (8)

c	m	E_{18}	E_{25}
5.41	6.12	2.0281	2.0283
3.0	3.196	2.0770	2.0784
1.0	1.022	2.1398	2.1430
0.5	0.5034	2.1724	2.1769
0.1	0.1003	2.2466	2.2527
0.02	0.02003	2.2306	2.3267
0.01	0.01001	2.3520	2.3585

Ag | AgCl | NaCl(c) | NaCl(0.001674c) | AgCl | Ag +

c	0.03344	0.01673	0.01117	0.008364	0.006686	(92)
E_{18}	0.05614	0.04360	0.03608	0.03073	0.02652	

Ag | AgCl | NaCl(c_1) | NaCl(c_2) | AgCl | Ag +

c_1	0.04972	0.03973	0.02985	0.01985	(93)
c_2	0.01984	0.01984	0.009909	0.009909	
E_{13}	0.01648	0.01232	0.02019	0.01257	

Hg | HgCl | NaCl(c_1) | NaCl(c_2) | HgCl | Hg +

c_2 = 0.1	c_1	0.3	0.5	1	2	3	(73)
	E_{25}	0.01991	0.02912	0.04202	0.05611	0.06530	
c_1 = 6.12 satd.	c_2			1.0	0.1		(142)
	E_{25}			0.0413	0.0831		

Ag | AgCl | NaCl(c_1), $NaNO_3$(2c) | $NaNO_3$(2c), NaCl(c_2) | AgCl | Ag +

c_1	c_2	E_{20}	Lit.
0.1001	0.01011	0.05776	(29)
0.01011	0.001110	0.05591	

NaBr

Ag | AgBr | NaBr(m) | Na_xHg | NaBr(0.1m) | AgBr | Ag + (81)

m	E_{25}	m	E_{25}	m	E_{25}
0.03	−0.0572	0.5	0.0773	2	0.1508
0.05	−0.0327	1	0.1123	2.5	0.1659
0.3	0.0524	1.5	0.1345	3	0.1779

Hg | HgBr | NaBr(0.125c) | NaBr(0.0125c) | HgBr | Hg +
E_{18} = 0.0417 (141)

NaI

Ag | AgI | NaI(m) | Na_xHg | NaI(0.1m) | AgI | Ag + (81)

m	E_{25}	m	E_{25}	m	E_{25}
0.03	−0.0572	0.5	0.0786	1	0.1147
0.3	0.0537				

Na_2SO_4

Hg | Hg_2SO_4 | Na_2SO_4(m) | Na_xHg | Na_2SO_4(0.05m) | Hg_2SO_4 | Hg + (7)

m	E_{25}	m	E_{25}	m	E_{25}
0.025	−0.0202	0.495	0.0634	1.438	0.0909
0.125	0.0255	0.975	0.0809	1.882	0.0961
0.249	0.0452				

KOH

H_2 | KOH(c_1) | K_xHg | KOH(c_2) | H_2 + (99)

c_1	c_2	E_{25}	c_1	c_2	E_{25}
3.000	0.2915	0.1416	0.300	0.0299	0.1110
2.955	0.2963	0.1395	0.0992	0.00989	0.1110
0.992	0.0996	0.1172	0.0996	0.00984	0.1110
0.995	0.0992	0.1170	0.0288	0.00286	0.1120
0.992	0.0996	0.1169	0.0299	0.00293	0.1130
0.300	0.0998	0.05361	0.0100	0.000991	0.1147
0.300	0.1000	0.05345	0.0100	0.001000	0.1149
0.2963	0.0282	0.1138			

H_2 | KOH(m_1) | KOH(m_2) | H_2 + (100)

m_1	m_2	E_{25}	m_1	m_2	E_{25}
3.0	0.3	0.03683	0.3	0.03	0.02916
1.0	0.1	0.03104	0.1	0.01	0.03465
0.3	0.1	0.01424			

H_2 | KOH, K_2SO_4 | K_xHg | KOH | H_2 + (7)
KOH, m = 0.01 and 0.1; K_2SO_4, c = 0.0 to 0.625; 25°C

H_2 | KOH, KX | K_xHg | KOH | H_2 +

KOH	KX	t, °C	Lit.
m = 0.01 and 0.1	KCl, m = 0.0 to 3.1	25	(77)
m = 0.1	KBr, m = 0.0 to 3.1	25	(84)
	KI, m = 0.0 to 3.1	25	(84)

KCl

Ag | AgCl | KCl(c_1) | K_xHg | KCl(c_2) | AgCl | Ag+ (131)

c_1	c_2	x	E_{25}	c_1	c_2	x	E_{25}
0.5	0.05	0.02	0.10735	0.1	0.01	0.002	0.10900
0.5	0.05	0.002	0.10745	0.05	0.005	0.004	0.11085
0.1	0.01	0.004	0.10885	0.05	0.005	0.002	0.11085

KCl.—(*Continued*)

Ag | AgCl | KCl(c_1) | KCl(c_2) | AgCl | Ag+ (92)

c_1	c_2	E_{18}	c_1	c_2	E_{18}
0.03347	0.003347	0.05403	0.01669	0.001670	0.05424
0.01669	0.003347	0.03806	0.01114	0.001670	0.04497
0.01117	0.003347	0.02856	0.008329	0.001670	0.03844
0.008350	0.003347	0.02175	0.006700	0.001670	0.03330
0.006696	0.003347	0.01643	0.005569	0.001670	0.02895
0.03349	0.001670	0.07028			

c_1	c_2	E_{25} (131)	c_1	c_2	E_{18} (93)
0.5	0.05	0.05357	0.04985	0.01969	0.02106
0.1	0.01	0.05400	0.03995	0.01969	0.01644
0.05	0.005	0.05473	0.03000	0.009924	0.02546
0.01	0.001	0.0560	0.01992	0.009924	0.01614

Ag | AgCl | KCl(satd.) | KCl(0.2775c) | AgCl | Ag+ (27)

t, °C..	0	14.2	30.1	45.2	60.2	76.0	90.3
E.....	0.0562	0.0637	0.0712	0.0782	0.0850	0.0917	0.0968

Hg | HgCl | KCl(c_1) | KCl(0.1c) | HgCl | Hg+ (72); *cf.* (62).

c_1	E_{25}	c_1	E_{25}
0.160	0.01044	0.700	0.04443
0.200	0.01536	1.000	0.05287
0.220	0.01802	1.300	0.05910
0.300	0.02475	1.900	0.06843
0.340	0.02785	2.500	0.07572
0.500	0.03637	3.100	0.08165

Ag | AgCl | KCl(0.5c) | K_xHg | KCl(0.1c), sucrose(C) | AgCl | Ag+

C, g/100 cm³	E_{25} (38)	C, g/100 cm³	E_{25} (38)
0	0.0740	40	0.0600
10	0.0706	50	0.0556
20	0.0674	60	0.0510
30	0.0642	70	0.0455

Ag | AgCl | KCl(0.5c) | KCl(0.1c), sucrose(C) | AgCl | Ag+
Ag | AgCl | KCl(0.5c), sucrose(C) | KCl(0.1c) | AgCl | Ag+

First cell (39)				Second cell (39)			
C*	E_{25}	C*	E_{25}	C*	E_{25}	C*	E_{25}
0	0.0368	40	0.0300	0	0.0368	40	0.0435
10	0.0352	50	0.0281	10	0.0384	50	0.0454
20	0.0335	60	0.0261	20	0.0401	60	0.0474
30	0.0319	70	0.0240	30	0.0418	70	0.0496

* g/100 cm³.

Ag | AgCl | KCl(c_1), KNO_3(c_2) | KNO_3(c_2), KCl(0.002c) | AgCl | Ag+

Values of E_{25} (157, 158)

c_1 \ c_2	0.005	0.01	0.02	0.04
0.01	0.0392	0.0401	0.0391	0.0392
0.02	0.0544	0.0573	0.0567	0.0559
0.04	0.0712	0.0724	0.0723	0 0725

Ag | AgCl | KCl(c_1), KNO_3(2c) | KNO_3(2c), KCl(c_2) | AgCl | Ag+ (29)

c_1.....	0.2	0.1	0.05
c_2.....	0.1	0.05	0.025
E_{20}.....	0.01744	0.01757	0.01746

KBr

Ag | AgBr | KBr(m) | K_xHg | KBr(0.1m) | AgBr | Ag+ (81)

m	E_{25}	m	E_{25}	m	E_{25}
0.05	−0.0324	1	0.1068	2	0.1410
0.3	0.0513	1.5	0.1266	2.5	0.1531
0.5	0.0746				

K_xHg | KBr(c) | AgBr | Ag + (152)
c = 0.001 to 2.5; 25, 30, 35°C

Ag | AgBr | KBr(m_1) | KBr(m_2) | AgBr | Ag+ (152)
m_1 = 0.01 to 2.8; m_2 = 0.001 to 0.25; 25, 30, 35°C

+Hg | HgBr | KBr(c_1) | KBr(c_2) | HgBr | Hg (45)

c_1	c_2	E_{18}	c_1	c_2	E_{18}
0.00202	0.00996	0.0391	0.00996	0.02004	0.0161
0.00202	0.02004	0.0569	0.00996	0.4004	0.0851
0.00202	0.04004	0.0717	0.02004	0.4004	0.0161
0.00202	0.1204	0.0971	0.04004	0.1204	0.0251
0.00202	0.4004	0.1242	0.1204	0.4004	0.0272

KI

Ag | AgI | KI(m) | K_xHg | KI(0.1m) | AgI | Ag+ (81)

m	E_{25}	m	E_{25}	m	E_{25}
0.3	0.0522	1	0.1092	2	0.1447
0.5	0.0758				

Ag | AgI | KI(c_1) | KI(c_2) | AgI | Ag+

c_1	c_2	E	Lit.
0.1	0.01	0.0536	(109)
0.01	0.001	0.0552	

Ag | AgI | KI(c_1) in H_2O | KI(0.001c) in C_2H_5OH | AgI | Ag (109)

c_1	E_{25}	c_1	E_{25}
0.001	0.080	0.02	±0.000
0.0025	0.049	0.04	−0.016
0.005	0.034	0.06	−0.027
0.0075	0.025	0.08	−0.033
0.01	0.017	0.10	−0.041

K_2SO_4

Hg | Hg_2SO_4 | K_2SO_4(m) | K_xHg | K_2SO_4(0.05m) | Hg_2SO_4 | Hg+ (7)

m	E_{25}	m	E_{25}	m	E_{25}
0.025	−0.0198	0.248	0.0420	0.621	0.0654
0.125	0.0241	0.494	0.0601		

$KAg(CN)_2$

Ag | $KAg(CN)_2$(c_1), KCN(c_2) | KCN(c_3) | $KAg(CN)_2$(c_4) | Ag
c_1 = 0.0₃5 to 0.05; c_2 and c_3 = 0.02 to 1.0; c_4 = 0.0₃25 to 0.025; room temp. (18)

Non-Aqueous Solutions

Solvent	Electrolyte	t	Lit.
NH_3.....	Na	−33	(102)
CH_3OH.....	HCl	25	(145)
CH_3OH.....	$AgNO_3$	25	(64)
$CH_3OH + H_2O$.....	$AgNO_3$	0 and 25	(149)
$CH_3OH + H_2O$.....	NaOH	18	(179)
$CH_3OH + H_2O$.....	KCl	10 to 40	(26)
$CH_3OH + H_2O$.....	KBr	10 to 40	(26)
C_2H_5OH.....	HCl	25	(42, 70, 82, 83, 106)
C_2H_5OH.....	$AgNO_3$	25	(11)
C_2H_5OH.....	LiCl	25	(49)
C_2H_5OH.....	$NaOC_2H_5$	25	(42)
C_2H_5OH.....	NaBr	25	(49)

NON-AQUEOUS SOLUTIONS.—(*Continued*)

Solvent	Electrolyte	t	Lit.
$C_2H_5OH + H_2O$	HCl	25	(82, 83)
$C_2H_5OH + H_2O$	$AgNO_3$	40	(103)
$C_2H_5OH + H_2O$	$AgNO_3$	0 and 25	(149)
$C_2H_5OH + H_2O$	KCl	10 to 40	(26)
$C_2H_5OH + H_2O$	KBr	10 to 40	(26)
$C_2H_5OH + CH_3OH$	$AgNO_3$	0 and 25	(149)
$(CH_3)_2CO$	$AgNO_3$	25	(64)
$C_3H_8O_3 + H_2O$	HCl	25	(125, 126)
C_5H_5N	$AgNO_3$	25	(64, 160)
$C_5H_5N + H_2O$	$AgNO_3$	25	(138)
$C_5H_5N + CH_3OH$	$AgNO_3$	25	(138)
$C_5H_5N + C_2H_5OH$	$AgNO_3$	25	(138)
$C_6H_5NH_2$	$AgNO_3$	25	(64)
$NaNO_3$	$AgNO_3$	400	(68)

II. CELLS WITH SALT BRIDGES

The calomel electrode is the reference electrode except as otherwise indicated; Ac = CH_3COO, the acetate radical

AQUEOUS SOLUTIONS

Cations, standard arrangement; *v.* Vol. III, p. viii

Solutes	t, °C	Lit.
H^+(or OH^-), H_2 electrode		
HF	25	(184)
HCl	25	(165)
HCl(+glycerol)	25	(36)
HCl(+sucrose)	25, 35	(39, 137, 166)
HCl(+HAc)	25	(116)
HCl(+salts)	20, 25	(5, 23, 65, 71, 74, 78, 80, 135)
$HCl(KHCO_3 + K_2CO_3 + KCl)$	25	(181)
$HClO_4$	25	(170)
HBr(+salts)	16–18	(9, 153)
H_2SO_4(+sucrose)	20, 40	(94)
H_2SO_4(+salts)	19	(5, 7)
HNO_3(+salts)	19	(5)
HAc(+NaAc)	18	(35, 182, 183)
HAc(+NaAc + NaCl + HCl)	18	(183)
HAc(+salts)	16	(161)
HAc(+sucrose)	35	(52, 116)
Palmitic acid + NaOH + NaCl	90	(129)
Na soaps	90	(129)
K soaps	90	(129)
NaOH	30	(58, 123)
NaOH(+glycerol)	25	(36)
NaOH(+sucrose)	35	(52)
NaOH(+salts)	25	(71, 78)
KOH(+salts)	25	(71, 78)
$KH_2PO_4 + K_2HPO_4$	25	(34)
H^+(or OH^-), Quinhydrone electrode		
HCl(+KCl)	18	(168, 169)
$HCl(+MgSO_4)$	18	(169)
$CHCl_2CO_2H$	18	(169)
$(+MgSO_4)$	18	(169)
$(+CCl_2HCO_2Na)$	18	(169)
(+KCl)	18	(169)
H^+(or OH^-), Ag | Ag_2O electrode		
$Ba(OH)_2$	25	(2)
Sn^{++}, Sn electrode		
$Sn(NO_3)_2$	25	(159)

II. CELLS WITH SALT BRIDGES.—(*Continued*)

Solutes	t, °C	Lit.
Pb^{++}, Pb electrode		
$Pb(ClO_3)_2$*	25	(112)
$Pb(NO_3)_2$*	25	(40, 89, 90, 112, 159)
$PbAc_2$*	25	(105)
In^{+++}, In electrode		
$InCl_3$	25	(178)
Tl^+, Tl electrode		
TlOH	25	(4)
TlCl	25	(4)
TlCl(satd.)	0, 25	(95)
TlCl(satd.)	25†	(114)
Tl_2SO_4	25	(4)
$TlNO_3$	17, 25	(4, 25)
Zn^{++}, Zn electrode		
$ZnCl_2$(+KCl)	Room	(105)
$ZnSO_4$	25	(98)
$ZnSO_4(0.5N)$	15–25‡	(98)
$ZnSO_4(+Na_2SO_4)$	Room	(105)
$ZnAc_2$(+NaAc)	Room	(105)
$Zn(CN)_2$(+KCN)	18	(175)
Cd^{++}, Cd electrode		
$CdCl_2$	Room	(105)
$CdSO_4(+Na_2SO_4)$	Room	(105)
$CdAc_2$(+NaAc)	25	(90)
Hg^{++}, Hg electrode		
$HgBr_2$	25	(172, 173)
HgI_2(+KI)	25	(172, 173)
HgS(+Na_2S)	25	(101)
$Hg(NO_2)_2(+KNO_2)$	25	(3)
$Hg(CN)_2$(+KCN + KOH)	25	(148)
Cu^{++}, Cu electrode		
$CuSO_4(+Na_2SO_4)$	Room	(105)
$CuSO_4(+KNO_3)$	Room	(88)
$Cu(NO_3)_2(+KNO_3)$	Room	(105)
$CuAc_2$(+NaAc)	Room	(105)
$Cu(CN)_2$(+KCN)	18	(175)
Ag^+, Ag electrode		
AgCl(+KCl)	25§	(55)
AgCl(+NaCl)	25§	
AgI(+KI)	Room	(17, 18)
$Ag_2SO_4(+MgSO_4)$	20‖	(29)
$AgNO_2(+KNO_2)$	25	(3)
$AgNO_3$	17	(25)
	25	(167)
	30	(111)
$AgNO_3(+KNO_3)$	20‖	(29)
AgAc	17	(25)
AgSCN(+KSCN)	Room§	(17, 18)
$KAg(CN)_2$(+KCN)	Room§	(17, 18)
$Ag_2CO_3(+KHCO_3 + K_2CO_3 + KCl)$	25	(181)
Co^{++}, Co electrode		
$CoCl_2$(+KCl)	Room	(105)
$CoSO_4(+Na_2SO_4)$	Room	(105)
Ni^{++}, Ni electrode		
$NiCl_2$	20	(171)
$NiSO_4$	Room	(171)
Ca^{++}, Ca_xHg electrode		
$CaCl_2$	21	(47)
CaI_2	21	(47)

II. CELLS WITH SALT BRIDGES.—(*Continued*)

Solutes	*t*, °C	Lit.
Li^+, Li amalgam electrode		
LiCl	22	(48)
$LiClO_4$	22	(48)
Li_2SO_4	23	(48)
Na^+, Na amalgam electrode		
Na_2SO_4	18	(48)

Anions

Solutes	*t*, °C	Ref. electrode	Lit.
X^-, Ag | AgX electrode (X = halogen)			
HCl(+sucrose)	25	Ag | AgCl	(39)
$AlBr_3$	25	Ag | $AgNO_3$(0.1*N*)	(96)
KI	25	Hg | HgCl	(109)
KBr	25	Ag | AgBr	(45)
I^-, I_2 electrode			
KI	25	Hg | HgCl	(95)
KI + I_2	25	Hg | HgCl	(134)
CdI_2 + I_2	25	I_2, KI	(180)
I^-,Pb | PbI_2 electrode			
KI	25	Hg | HgCl	(113)
IO_3^-,Ag | $AgIO_3$ electrode			
KIO_3	25, 60	Ag | $AgNO_3$	(162)
CO_3^{--},Ag | Ag_2CO_3 electrode			
Na_2CO_3	25	Hg | HgCl	(174)
$C_2O_4^{--}$,Ag | $Ag_2C_2O_4$ electrode			
$K_2C_2O_4$	25	Hg | HgCl	(167)
KHC_2O_4	25	Hg | HgCl	(167)
$KH_3(C_2O_4)_2$	25	Hg | HgCl	(167)

Molecules

Cl_2, Cl_2 electrode

Cl_2 at various concentrations in 0.5*N* HCl against 0.1*N* calomel electrode (177).

* Also + the corresponding alkali metal salts.
† Tl \| $TlNO_3$, ref. electrode
‡ Hg \| Hg_2SO_4, ref. electrode.
‖ Ag \| AgCl, ref. electrode.
§ Ag \| $AgNO_3$, ref. electrode.

Non-Aqueous Solutions

Reference electrode, Hg \| HgCl

H^+, H_2 electrode

HCl(+KCl) at 25° in C_2H_5OH (and + H_2O) (14, 136).

Ag^+, Ag electrode

$AgNO_3$ at 25° in mixtures of H_2O with CH_3OH, C_2H_5OH, and pyridine and in CH_3OH + pyridine, and C_2H_5OH + pyridine (138, 149).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abegg, Auerbach and Luther, *533*, **2**: No. 5; 11. (2) Abegg and Cox, *7*, **46**: 1; 03. (3) Abegg and Pick, *93*, **51**: 1; 06. (4) Abegg and Spencer, *93*, **46**: 406; 05. (5) Åkerlöf, *7*, **98**: 260; 21. (6) Åkerlöf, *147*, **6**: No. 2; 25. (7) Åkerlöf, *1*, **48**: 1160; 26. (8) Allmand and Polack, *4*, **115**: 1020; 19. (9) Arkadiev, *7*, **104**: 192; 23.

(10) Auerbach, *533*, **2**: No. 8; 15. (Erster Ergänz.) (11) Bell and Feild, *1*, **35**: 715; 13. (12) Biron, *53*, **39**: 1506; 07. **40**: 79; 08. (13) Biron and Afanasjev, *53*, **41**: 1175; 09. (14) Bjerrum, *7*, **53**: 428; 05. (15) Bodenstein and Geiger, *7*, **49**: 70; 04. (16) Bodländer, *in B98*, p. 153. (17) Bodländer, *25*, **36**: 3933; 03. (18) Bodländer and Eberlein, *93*, **39**: 197; 04. (19) Bodländer and Fittig, *7*, **39**: 597; 02.

(20) Bodländer and Storbeck, *93*, **31**: 1; 02. (21) Bodländer and Storbeck, *93*, **31**: 458; 02. (22) Bonsdorff, *25*, **36**: 2322; 03. *93*, **41**: 132; 04. (23) Bowe, *50*, **31**: 291; 27. (24) Bray, *1*, **49**: 2372; 27. (25) Brislee, *83*, **4**: 159; 09. (26) Brodskii, *7*, **121**: 1; 26. (27) Brönsted, *7*, **56**: 645; 06. (28) Brönsted, *7*, **68**: 693; 10. (29) Brönsted, *137*, **3**: No. 9; 20.

(30) Carhart, *2*, **26**: 209; 08. (31) Carter and Lea, *4*, **127**: 487; 25. (32) Chow, *1*, **42**: 497; 20. (33) Cohen, Chattaway and Tombrock, *7*, **60**: 706; 07. (34) Cohn, *1*, **49**: 173; 27. (35) Cohn, Heyroth and Menkin, *1*, **50**: 696; 28. (36) Colvin, *4*, **127**: 2788; 25. (37) Conrad, *Diss.*, Göttingen, 1903. (38) Corran, *1*, **45**: 1627; 23. (39) Corran and Lewis, *1*, **44**: 1673; 22.

(40) Cumming, *83*, **2**: 213; 07. (41) Cumming and Abegg, *9*, **13**: 17; 07. (42) Danner, *1*, **44**: 2832; 22. (43) Dolezalek, *7*, **26**: 321; 98. (44) Dolezalek, *9*, **5**: 533; 99. (45) Drucker, *9*, **18**: 562; 12. (46) Drucker, *9*, **19**: 797; 13. (47) Drucker and Luft, *7*, **121**: 307; 26. (48) Drucker and Riethof, *7*, **111**: 1; 24. (49) Drucker and Schingnitz, *7*, **122**: 149; 26.

(50) Edgar, *Thesis*, Mass. Inst. Tech., 1912. (51) Ellis, *1*, **38**: 737; 16. (52) Fales and Morrell, *1*, **44**: 2071; 22. (53) Ferguson and France, *1*, **43**: 2150; 21. (54) Ferguson and France, *1*, **43**: 2161; 21. (55) Forbes and Anderegg, *1*, **37**: 1676; 15. (56) Foxton and Shutt, *83*, **23**: 480; 27. (57) France and Moran, *1*, **46**: 19; 24. (58) Fricke, *9*, **26**: 129; 20. (59) Geissler, *9*, **18**: 131; 12.

(60) Gelbach and Huppke, *1*, **48**: 1504; 26. (61) Getman, *78*, **26**: 67; 14. (62) Getman, *1*, **42**: 1556; 20. (63) Getman, *50*, **32**: 91; 28. (64) Gibbons and Getman, *1*, **36**: 1630; 14. (65) Gillespie and Wise, *1*, **40**: 796; 18. (66) Goodwin, *7*, **13**: 577; 94. (67) Goodwin, *2*, **4**: 242; 97. (68) Goodwin, *78*, **21**: 105; 12. (69) Güntelberg, *7*, **123**: 199; 26.

(70) Hardman and Lapworth, *4*, **101**: 2249; 12. (71) Harned, *1*, **37**: 2460; 15. (72) Harned, *1*, **38**: 1986; 16. (73) Harned, *1*, **40**: 1461; 18. (74) Harned, *1*, **42**: 1808; 20. (75) Harned, *1*, **47**: 676; 25. (76) Harned, *1*, **47**: 684; 25. (77) Harned, *1*, **47**: 689; 25. (78) Harned, *50*, **30**: 433; 26. (79) Harned, *1*, **48**: 326; 26.

(80) Harned and Brumbaugh, *1*, **44**: 2729; 22. (81) Harned and Douglas, *1*, **48**: 3095; 26. (82) Harned and Fleysher, *1*, **47**: 82; 25. (83) Harned and Fleysher, *1*, **47**: 92; 25. (84) Harned and James, *50*, **30**: 1060; 26. (85) Harned and Sturgis, *1*, **47**: 945; 25. (86) Harned and Swindells, *1*, **48**: 126; 26. (87) Horsch, *1*, **41**: 1787; 19. (88) Immerwahr, *93*, **24**: 269; 00. **25**: 112; 00. (89) Jacques, *83*, **5**: 212; 10.

(90) Jacques, *83*, **5**: 225; 10. (91) Jahn, *8*, **28**: 21, 491; 86. (92) Jahn, *7*, **33**: 545; 00. (93) Jahn, *7*, **50**: 129; 04. (94) Jones and Lewis, *4*, **117**: 1120; 20. (95) Jones and Schumb, *65*, **56**: 199; 21. (96) Kablukov and Sakhanov, *7*, **69**: 419; 09. (97) Kendrick, *9*, **7**: 52; 00. (98) Kistiakovskii, *9*, **14**: 113; 08. (99) Knobel, *1*, **45**: 70; 23.

(100) Knobel, Worcester and Briggs, *1*, **45**: 77; 23. (101) Knox, *9*, **12**: 477; 06. *83*, **4**: 29; 08. (102) Kraus, *1*, **36**: 864; 14. (103) Krumreich, *9*, **22**: 446; 16. (104) Kunschert, *93*, **41**: 337; 04. (105) Labendzinski and Abegg, *9*, **10**: 77; 04. (106) Lapworth and Partington, *4*, **99**: 1417; 11. (107) Laurie, *68*, **28**: 382; 08. (108) Laurie, *68*, **29**: 304; 09. (109) Laurie, *68*, **31**: 380; 11.

(110) Lehfeldt, *7*, **35**: 257; 00. (111) Lewis, *1*, **28**: 158; 06. *7*, **55**: 465; 06. (112) Lewis, *7*, **63**: 171; 08. *Diss.*, Breslau, 1908. (113) Lewis and Brighton, *1*, **39**: 1906; 17. (114) Lewis and von Ende, *1*, **32**: 732; 10. (115) Lewis and Lacey, *1*, **36**: 804; 14. (116) Lewis, Merriman and Moran, *1*, **45**: 702; 23. (117) Lewis and Rupert, *1*, **33**: 299; 11. (118) Lewis and Storch, *1*, **39**: 2544; 17. (119) Linhart, *1*, **39**: 2601; 17.

(120) Linhart, *1*, **41**: 1175; 19. (121) Livington, *1*, **48**: 45; 26. (122) Loomis, Essex and Meacham, *1*, **39**: 1133; 17. (123) Lorentz and Mohn, *7*, **60**: 422; 07. (124) Lucasse, *1*, **47**: 743; 25. (125) Lucasse, *50*, **30**: 562; 26. (126) Lucasse, *1*, **48**: 626; 26. (127) Luther, *7*, **30**: 628; 99. (128) Luther and Sammet, *9*, **11**: 293; 05. (129) McBain and Martin, *4*, **105**: 957; 14.

(130) MacInnes and Beattie, *1*, **42**: 1117; 20. (131) MacInnes and Parker, *1*, **37**: 1445; 15. (132) McIntosh, *50*, **2**: 185; 98. (133) McIntosh, *50*, **2**: 273; 98. (134) Maitland, *9*, **12**: 263; 06. (135) Michaelis and Mitzutani, *7*, **112**: 68; 24. (136) Millet, *83*, **23**: 515; 27. (137) Moran and Lewis, *4*, **121**: 1613; 22. (138) Mortimer and Pearce, *50*, **21**: 275; 17. (139) Müller, *7*, **40**: 158; 02.

(140) Mugdan, *9*, **6**: 309; 99. (141) Nernst, *7*, **4**: 129; 89. (142) Newbery, *4*, **107**: 1520; 15. (143) Nielsen and Brown, *1*, **49**: 2423; 27. (144) Nonhebel, *3*, **2**: 1085; 26. (145) Nonhebel and Hartley, *3*, **50**: 729; 25. (146) Noyes and Ellis, *1*, **39**: 2532; 17. (147) Ogg, *7*, **27**: 285; 98. (148) Palmaer, *7*, **59**: 129; 07. (149) Pearce and Farr, *50*, **18**: 729; 14.

(150) Pearce and Fortsch, *1*, **45**: 2852; 23. (151) Pearce and Gelbach, *50*, **29**: 1023; 25. (152) Pearce and Hart, *1*, **43**: 2483; 21. (153) Przeborowski, Fleissner and Sabrodina, *7*, **107**: 270; 23. (154) Randall and Breckenridge, *1*, **49**: 1435; 27. (155) Randall and Cushman, *1*, **40**: 393; 18. (156) Randall and Langford, *1*, **49**: 1445; 27. (157) Sackur, *7*, **38**: 129; 01. (158) Sackur, *9*, **7**: 781; 01. (159) Sackur, *291*, **20**: 512; 04.

(160) Sakhanov, *50*, **21**: 169; 17. (161) Sakhanov and Goncharov, *53*, **47**: 1249; 15. (162) Sammet, *7*, **53**: 641; 05. (163) Sauer, **7**, **47**: 146; 04. (164) Scatchard, *1*, **47**: 641; 25. (165) Scatchard, *1*, **47**: 696; 25. (166) Scatchard, *1*, **48**: 2026; 26. (167) Schäfer and Abegg, *93*, **45**: 293; 05. (168) Schreiner, *93*, **121**: 321; 22. (169) Schreiner, *93*, **122**: 201; 22.

(170) Schuhmann, *1*, **46**: 58; 24. (171) Schweitzer, *9*, **15**: 602; 09. (172) Sherrill, *7*, **43**: 705; 03. (173) Sherrill and Abegg, *9*, **9**: 549; 03. (174) Spencer and LePla, *93*, **65**: 10; 09. (175) Spitzer, *9*, **11**: 345; 05. (176) Stegmüller, *9*, **16**: 85; 10. (177) Sullivan, *7*, **28**: 523; 99. (178) Thiel, *93*, **40**: 280; 04. (179) Unmack, *7*, **131**: 371; 28.

(180) Van Name and Brown, *12*, **44**: 453; 17. (181) Walker, Bray and Johnston, *1*, **49**: 1235; 27. (182) Walpole, *4*, **105**: 2501; 14. (183) Walpole, *4*, **105**: 2521; 14. (184) Wynne-Jones and Hudleston, *4*, **125**: 1031; 24.

POTENTIALS OF ELECTROCHEMICAL REACTIONS

ROSCOE H. GERKE

The potential, E, of an electrochemical reaction is given by

$$E = E_0 - \frac{0.05915}{N} \log_{10} \frac{(A_P)^x}{(A_R)^y},$$

where N is the number of faradays of electricity in the equation of the reaction; A_P, resp. A_R, the activities of the products (resp. reactants) and x and y the corresponding coefficients in the electrochemical equation. In the following tables are recorded the values of E for the following conditions:

All molecular and ion species whose concentrations are not fixed by the nature of the phases present as shown by the reaction given are at the concentration at which their molal activities are unity (*i.e.*, "activity molal"), the activity coefficients being those given by Lewis and Randall (43); except for HCl, for which *v.* (85). All gases are present at $p = 1A_n$. For further details, *v.* (23).

In all cases the electrochemical reaction tends to take place from left to right as written, when opposed to an "activity-molal" hydrogen electrode. The increase in free energy, ΔF, attending the reaction is given by $\Delta F = -NFE$ where **F** is the value of the faraday.

The electromotive force of a cell composed of two electrodes with liquid junction potentials eliminated is equal to the difference between the potentials for electrochemical reactions of the same pole sign and is equal to the sum of the potentials for reactions of different pole signs.

Potentials of Electrochemical Reactions at 25°C

1. The electrode which is in equilibrium with respect to the electrochemical reaction is charged negatively (*i.e.*, pole sign is −).

Reaction	Volt	Lit.
$Li(s) = Li^+ + e$	2.9595	(43)
$Rb(s) = Rb^+ + e$	2.9259	(43)
$K(s) = K^+ + e$	2.9241	(43)
$Ca(s) = Ca^{++} + 2e$	2.763	(16)
$Na(s) = Na^+ + e$	2.7146	(43)
$BaHg = Ba^{++} + 2e$	1.5700	(14)
$NaHg + (Cl^-$ in NaCl satd.$) = NaCl(s) + e$	1.8378	(13)
$SrHg = Sr^{++} + 2e$	1.7932	(14)
$AlHg + 3OH^- = Al(OH)_3(s) + 3e$	1.62	(31)
$Zn(s) + 2OH^- = ZnO(s) + H_2O(l)$	1.2483	(81)
$\frac{1}{2}H_2(g) + OH^- = H_2O(l) + e$	0.8295	(43)
$ZnHg + (SO_4^{--}$ in $ZnSO_4.7H_2O$ satd.$) = ZnSO_4.7H_2O(s) + 2e$	.7993	(73)
$Tl(s) + I^- = TlI(s) + e$	.7715	(37)
$CdHg + 2OH^- = Cd(OH)_2(s) + 2e$	.761	(47)
$Zn(s) = Zn^{++} + 2e$	.7618	(43)
$CdHg + 2OH^- = CdO(s) + H_2O(l) + 2e$	.726	(47)
$TlHg + Br^- = TlBr(s) + e$	.6058	(41)
$Pb(s) + 2OH^- = PbO(s_{red}) + H_2O(l) + 2e$	.5786	(4, 71)
$Pb(s) + 2OH^- = PbO(s) + H_2O(l) + 2e$	.576	(21)
$Pb(s) + 2OH^- = PbO(s_{yellow}) + H_2O(l) + 2e$	.575	(4)
$PbHg + 2OH^- = Pb(OH)_2(s) + 2e$	.568	(24)
$Cr(s) = Cr^{++} + 2e$	.557	(28)
$TlHg + Cl^- = TlCl(s) + e$	.5545	(22)
$CdHg + (2I^-$ in CdI_2 satd.$) = CdI_2(s) + 2e$	.4588	(55, 77)
$Fe(s) = Fe^{++} + 2e$	.441	(43)
$TlHg + SO_4^{--} = Tl_2SO_4(s) + 2e$	.4360	(33)
$CdHg + (SO_4^{--}$ in $CdSO_4.\frac{8}{3}H_2O$ satd.$) = CdSO_4.\frac{8}{3}H_2O(s) + 2e$	.4346	(55)
$CdHg + (2Br^-$ in $CdBr_2.4H_2O$ satd.$) = CdBr_2.4H_2O(s) + 2e$	0.4182	(56)
$CdHg + (2Cl^-$ in $CdCl_2$ satd.$) = CdCl_2(s) + 2e$	.4034	(55)
$Cr^{++} = Cr^{+++} + e$	.400	(20, 28)
$Cd(s) = Cd^{++} + 2e$	.4013	(43)
$PbHg + 2I^- = PbI_2(s) + 2e$	.3591	(22)
$2Cu(s) + 2OH^- = Cu_2O(s) + H_2O(l) + 2e$	.344	(1)
$PbHg + SO_4^{--} = PbSO_4(s) + 2e$	.3433	(30)
$TlHg = Tl^+ + e$	.3360	(43)
$PbHg + 2Cl^- = PbCl_2(s) + 2e$	.2623	(22)
$Cu(s) + H_2S(g) = CuS(s) + 2H^+ + 2e$	.259	(39)
$Ni(s) = Ni^{++} + 2e$	.231	(79)
$Sb(s) + H_2O(l) = SbO^+ + 2H^+ + 3e$	.212	(69)
$VSO_4 + H_2O(l) = \frac{1}{2}(VO)_2SO_4 + 2H^+ + \frac{1}{2}SO_4^{--} + e$	.21	(65)
$Cu_2O(s) + 2OH^- = 2CuO(s_{aged}) + H_2O(l) + 2e$	.154	(2)
$Ag(s) + I^- = AgI(s) + e$	.151	(22, 53, 74)
$Sn(s) = Sn^{++} + 2e$	.136	(43)
$Pb(s) = Pb^{++} + 2e$	.122	(43)
$Cu_2O(s) + 2OH^- + H_2O(l) = 2Cu(OH)_2(s) + 2e$	.082	(1)
$2Hg(l) + 2I^- = Hg_2I_2(s) + 2e$	.0416	(77)
$2Ag(s) + H_2S(g) = Ag_2S(s) + 2H^+ + 2e$	.0366	(53)
$\frac{1}{2}H_2(g) = H^+ + e$	.0000	

2. The electrode which is in equilibrium with respect to the electrochemical reaction is charged positively (*i.e.*, pole sign is +).

Reaction	Volt	Lit.
$\frac{1}{2}H_2(g) = H^+ + e$	0.0000	
$Ti(SO_4)_2 + e = Ti^{+++} + 2SO_4^{--}$	.04	(15)
$PbS(s) + 2H^+ + 2e = Pb(s) + H_2S(g)$	.070	(39)
$AgBr(s) + e = Ag(s) + Br^-$	.0734	(45)
$HgO(s_{red}) + H_2O(l) + 2e = Hg(l) + 2OH^-$	.0969	(21, 43)
$HgO(s_{yellow}) + H_2O(l) + 2e = Hg(l) + 2OH^-$	.0976	(9)
$CuCl(s) + e = Cu(s) + Cl^-$	.1287	(51, 82)
$Hg_2Br_2(s) + 2e = 2Hg(l) + 2Br^-$	.1385	(25)
$Sb_2O_3(s) + 6H^+ + 6e = 2Sb(s) + 3H_2O(l)$	.1445	(69)
$BiOCl(s) + 2H^+ + 3e = Bi(s) + Cl^- + H_2O(l)$	.1588	(35, 51)
$AgCl(s) + e = Ag(s) + Cl^-$	.2221	(22, 50, 52, 68, 85)
$As_2O_3(s) + 6H^+ + 6e = 2As(s) + 3H_2O(l)$	.2340	(70)
$HAsO_2 + 3H^+ + 3e = As(s) + 2H_2O(l)$	.2375	(70)
$Hg_2Cl_2(s) + 2e = 2Hg(l) + 2Cl^-$	.2676	(43, 85)
$CuSO_4.5H_2O(s) + 2e = CuHg + (SO_4^{--}$ in $CuSO_4.5H_2O$ satd.$)$	.2684	(54, 57)
$PbO_2(s) + H_2O(l) + 2e = PbO(s) + 2OH^-$	.27	(27)
Normal calomel electrode	.2805	(85)
$VOSO_4 + e = \frac{1}{2}(VO)_2SO_4 + \frac{1}{2}SO_4^{--}$	.30	(65)
Decinormal calomel electrode	.3334	(85)
$Cu^{++} + 2e = Cu(s)$	.3441	(43)
$Cu^{++} + 2e = Cu$(satd. amalgam)	.3495	(49)
$UO_2SO_4 + 4H^+ + SO_4^{--} + 2e = U(SO_4)_2 + 2H_2O(l)$	.358	(46)

Reaction	Volt	Lit.
$Ti^{+++} + e = Ti^{++}$	0.37	(19)
$Cu^{++} + 2Cl^- + e = CuCl_2^-$	.455	(8)
$W(CN)_8^{---} + e = W(CN)_8^{----}$	.485	(11, 12)
$K_3Fe(CN)_6 + K^+ + e = K_4Fe(CN)_6$	.4866	(44)
$Ag_2CO_3(s) + 2e = 2Ag(s) + CO_3^{--}$	.500	(72)
$\frac{1}{2}I_2(s) + e = I^-$	.5345	(43, 80)
$H_3AsO_4 + 2H^+ + 2e = H_3AsO_3 + H_2O$	.574	(17)
$Hg_2SO_4(s) + 2e = 2Hg(l) + SO_4^{--}$	.6213	(43)
$MnO_4^- + e = MnO_4^{--}$	.664	(66)
$AgBrO_3(s) + e = Ag(s) + BrO_3^-$	.680	(59)
$PtCl_4^{--} + 2e = PtCl_4 + 2Cl^-$	.717	(48)
$Fe^{+++} + e = Fe^{++}$	.7477	(50, 84)
$Ag^+ + e = Ag(s)$	.7978	(43)
$Hg_2^{++} + 2e = 2Hg(l)$	.7986	(43)
$Mo(CN)_8^{---} + e = Mo(CN)_8^{----}$	.820	(11, 12)
$[Pt(CN)_4Cl_2]^{--} + 2e = [Pt(CN)_4]^{--} + 2Cl^-$	.879	(87)
$\frac{1}{2}Hg_2^{++} + e = Hg^{++}$	.9011	(83)
$HVO_3 + H_2SO_4 + e = VOSO_4 + 2H_2O(l)$	.92	(65)
$\frac{1}{2}Br_2(l) + e = Br^-$	1.0648	(43)
$IO_3^- + 6H + 5e = \frac{1}{2}I_2(s) + 3H_2O(l)$	1.197	(67)
$Tl^{+++} + 2e = Tl^+$	1.211	(29)
$Sn^{++++} + 2e = Sn^{++}$	1.256	(18)
$MnO_2(s) + 4H^+ + 2e = Mn^{++} + 2H_2O(l)$	1.332	(75)
$\frac{1}{2}Cl_2(g) + e = Cl^-$	1.3583	(22, 43)
$Au^{+++} + 3e = Au(s)$	1.36	(36)
$Au_2O_3(s) + 6H^+ + 6e = 2Au(s) + 3H_2O(l)$	1.363	(7, 26)
$BrO_3^- + 6H^+ + 5e = \frac{1}{2}Br_2(l) + 3H_2O(l)$	1.491	(67)
$Ce^{++++} + e = Ce^{+++}$	1.55	(5)
$MnO_4^- + 4H^+ + 3e = MnO_2(s) + 2H_2O(l)$	1.586	(6)
$PbO_2(s) + 4H^+ + SO_4^{--} + 2e = PbSO_4(s) + 2H_2O(l)$	1.6797	(38, 78)
$Co^{+++} + e = Co^{++}$	1.817	(34, 40)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Allmand, *4*, **95**: 2151; 09. (2) Allmand, *4*, **97**: 603; 10. (3) Allmand and Polack, *4*, **115**: 1020; 19. (4) Applebey and Reid, *4*, **121**: 2129; 22. (5) Baur and Glaessner, *9*, **9**: 534; 03. (6) Brown and Tefft, *1*, **48**: 1128; 26. (7) Buehrer and Roseveare, *1*, **49**: 1989; 27. (8) Carter and Lea, *4*, **127**: 499; 25. (9) Cohen, *7*, **34**: 69; 00.
(10) Cohen and Moesveld, *7*, **95**: 285; 20. (11) Collenberg, *7*, **109**: 353; 24. (12) Conant and Pratt, *1*, **48**: 3220; 26. (13) Danner, *1*, **44**: 2832; 22. (14) Danner, *1*, **46**: 2385; 24. (15) Diethelm and Foerster, *7*, **62**: 129; 08. (16) Drucker and Luft, *7*, **121**: 307; 26. (17) Foerster and Pressprich, *9*, **33**: 176; 27. (18) Forbes and Bartlett, *1*, **36**: 2030; 14. (19) Forbes and Hall, *1*, **46**: 385; 24.
(20) Forbes and Richter, *1*, **39**: 1140; 17. (21) Fried, *7*, **123**: 406; 26. (22) Gerke, *1*, **44**: 1684; 22. (23) Gerke, *286*, **1**: 377; 25. (24) Gerke, *0*. (25) Gerke and Geddes, *50*, **31**: 886; 27. (26) Gerke and Rourke, *1*, **49**: 1855; 27. (27) Glasstone, *4*, **121**: 1456; 22. (28) Grube and Breitinger, *9*, **33**: 112; 27. (29) Grube and Hermann, *9*, **26**: 291; 20.
(30) Henderson and Stegeman, *1*, **40**: 84; 18. (31) Heyrovsky, *4*, **117**: 27; 20. (32) Hulett, *78*, **7**: 333; 05. (33) Ishikawa, *41*, **43**: 560; 22. (34) Jahn, *93*, **60**: 292; 08. (35) Jellinek and Kühn, *7*, **105**: 337; 23. (36) Jirsa and Jellinek, *362*, **18**: 1; 24. *9*, **30**: 286; 24. (37) Jones and Schumb, *65*, **56**: 199; 21. (38) Kendrick, *9*, **7**: 52; 01. (39) Knox, *83*, **4**: 29; 08.
(40) Lamb and Larson, *1*, **42**: 2024; 20. (41) Lewis and von Ende, *1*, **32**: 732; 10. (42) Lewis and Kraus, *1*, **32**: 1459; 10. (43) Lewis and Randall, *Thermodynamics and the free energy of chemical substances*. New York, McGraw-Hill, 1923. (44) Lewis and Sargent, *1*, **31**: 355; 09. (45) Livingston, *1*, **48**: 45; 26. (46) Luther and Michie, *9*, **14**: 826; 08. (47) McRay, *Thesis*, Mass. Inst. Tech., 1917. (48) Miller and Terrey, *4*, **1927**: 605. (49) Nielsen and Brown, *1*, **49**: 2423; 27.
(50) Noyes and Brann, *1*, **34**: 1016; 12. (51) Noyes and Chow, *1*, **40**: 739; 18. (52) Noyes and Ellis, *1*, **39**: 2532; 17. (53) Noyes and Freed, *1*, **42**: 476; 20. (54) Obata, *219*, **2**: 223; 20. (55) Obata, *219*, **3**: 64; 21. (56) Öholm, *426*, **41**: No. 1; 13. (57) Öholm, *147*, **5**: No. 4; 19. (58) Pearce and Fortsch, *1*, **45**: 2852; 23. (59) Reedy, *1*, **43**: 1440; 21.
(60) Richards and Conant, *1*, **44**: 601; 22. (61) Richards and Daniels, *1*, **41**: 1732; 19. (62) Richards and Lewis, *7*, **28**: 1; 99. (63) Richards and Smyth, *1*, **44**: 524; 22. (64) Roberts and Fenwick, *1*, **49**: 2787; 27. (65) Rutter, *93*, **52**: 368; 07. (66) Sackur and Taegener, *9*, **18**: 718; 12. (67) Sammet, *7*, **53**: 641; 05. (68) Scatchard, *1*, **47**: 641; 25. (69) Schuhmann, *1*, **46**: 52; 24.
(70) Schuhmann, *1*, **46**: 1444; 24. (71) Smith and Woods, *1*, **45**: 2632; 23. (72) Spencer and LePla, *93*, **65**: 10; 09. (73) Steinwehr, *243*, **33**: 321; 13. (74) Taylor and Perrott, *1*, **43**: 484; 21. (75) Tower, *7*, **32**: 566; 00. (76) Vosburgh, *1*, **47**: 2531; 25. (77) Vosburgh, *1*, **50**: 2386; 28. (78) Vosburgh and Craig, State Univ. of Iowa, Iowa City, *0*. (79) Haring and Vanden Bosche, *50*, **33**: 161; 29.
(80) Jones and Kaplan, *1*, **50**: 2066; 28. (81) Maier, Parks and Anderson, *1*, **48**: 2564; 26. (82) Neilson and Brown, *1*, **50**: 9; 28. (83) Popoff, State Univ. of Iowa, Iowa City, *0*. (84) Popoff and Kunz, *1*, **51**: 382; 29. (85) Randall and Young, *1*, **50**: 989; 28. (86) Roberts and Fenwick, *1*, **50**: 2125; 28. (87) Terry, *4*, **1928**: 202.

ELECTROMOTIVE FORCE OF CELLS INVOLVING THE OXIDATION AND REDUCTION OF ORGANIC COMPOUNDS

J. B. Conant

In Table 1 is listed the electromotive force of reversible cells corresponding to the chemical reaction A (dis.) $+H_2 \rightleftarrows AH_2$ (dis.). The recorded emf is either the directly measured emf of cell 1 or is calculated from the emf's of cells 2 and 3, on the assumption that the liquid junction potentials cancel.

(1) [Pt] H_2(1 atm.) | $H^+(c_H)$ | $H^+(c_H)$, $A(c_1)$, $AH_2(c_1)$ | Pt+

(2) [Pt] H_2(1 atm.) | $H^+(c_H)$ | *N* KCl | HgCl | Hg+

(3) Hg | HgCl | *N* KCl | $H^+(c_H)$, $A(c_1)$, $AH_2(c_1)$ | Pt+

The compounds listed in Table 1 are such that in the acid solutions employed the dissociation of AH_2 into A^{--} or AH^- is negligible. Three methods have been employed in order to measure the emf: (1) the two substances have been added in known amounts; (2) the quinhydrone ($A \cdot AH_2$) has been introduced into the cell; (3) the oxidized form has been titrated with a reducing agent (usually titanous chloride) and the mid-point of the titration curve determined graphically ($[A] = [AH_2]$). The three methods are designated in the tables as M, Q, and T, respectively. In a few cases the solution has been saturated with both A and AH_2, or with one of these substances and the corresponding quinhydrone ($A \cdot AH_2$). These results have been listed in Table 2; from them may be calculated the free energy change of the reaction, A(solid) $+ H_2 \rightleftarrows AH_2$(solid). The free energy change of the reaction A(gas) $+ H_2 \rightleftarrows AH_2$(gas) has been calculated for all the chloroquinones and xyloquinone (13).

(1, 4, 37) should be consulted for the measurement of the emf of cells of type 4 in various buffer solutions and the changes in emf due to variations in activity of the quinone and hydroquinone caused by the presence of salts.

(4) Hg | HgCl | KCl(satd.) | $H^+(c_H)$, quinhydrone | Pt+

For the application of the "quinhydrone electrode" to the determination of hydrogen ion activity in aqueous solution, *see* p. 330; and for solutions in absolute methyl alcohol, *v.* (26).

The relation of the emf's in aqueous and alcoholic solutions and slight changes due to the total acid concentration are dealt with in (16, 17, 18).

In Table 3 are summarized data concerning the emf of cells of type 5 in which the reaction for one reason or another does not correspond to the simple equation $A + H_2 \rightleftarrows AH_2$, for the entire range of $[H^+]$ investigated.

(5) [Pt] | H_2(1 atm.) | N H^+ | KCl(satd.) | $H^+(c_H)$, $A(c_1)$, $AH_2(c_1)$ | Pt+

Such results as were obtained with varying values of $[H^+] = c_H$ maintained by appropriate "buffer solutions," are best expressed in the form of equations involving $[H^+]$ and certain experimentally determined constants. These constants and the equations are given in Table 3. The "normal oxidation-reduction potential' in a given $[H^+]$ may be defined as the emf of cell 5. In calculating such potentials from the experimental results, liquid junction potentials have been ignored and the value of the hydrogen electrode in $N/20$ acid potassium phthalate at 30° taken as 0.2386 volt.

For further details concerning the derivation of equations for oxidation-reduction potentials in solutions of varying $[H^+]$, (6, 7, 8) should be consulted. Preliminary data in regard to measurements of certain indophenols in one or two buffer solutions are given in (12), and a few preliminary measurements with certain sulfonated dyestuffs in pH = 0.76 to 12.7 and in non-aqueous solvents are given in (20, 21). The potential of the reversible system hemoglobin-methemoglobin is given in (24), of quinone-imine-phenylenediamine in (23), of triphenylmethyl-triphenylmethyl sulfate in (25). For a study of meriquinones of the phenylenediamine and benzidine series, *see* (10); for certain indamine dyes, *see* (35).

For a discussion of the errors inherent in the titration method, *see* (34); for a comparison of the titration method and method of mixtures, *see* (8, 11, 38).

For methods of estimating the "apparent reduction potential" and "apparent oxidation potential" of irreversible processes and other applications of reversible systems to the study of oxidation-reduction processes, *see* (14, 20, 21, 22, 23).

TABLE 1

Emf of cell: [Pt] | H_2(1 atm. dry) | HCl(c_H) | HCl(c_H), $A(c_1)$, $AH_2(c_2)$ | Pt+

Concn. of organic material, 0.001–0.005N. Quinones: the name of the oxidized compound, A, is listed; the reduced compound in every case was the corresponding hydroquinone. The probable error is 1–3 in the last place except in the values followed by a dagger, where the error may be as great as 5 millivolts.

A	t, °C	0.1N HCl (aqueous), volt	Method	Lit.	0.5N HCl,* 50 % C_2H_5OH, volt	Method	Lit.	0.5N HCl, 95 % C_2H_5OH, volt	Method	Lit.
1, 4-Quinone	0	0.7172	Q	(3)	0.734	T	(16)			
	18	0.7044	Q	(1)	[0.724 in abs. CH_3OH]				Q	(26)
	25	0.6990	Q, M, T	(1, 33, 34)	0.713	T	(16)	0.711	T	(16)
	37	0.690	Q	(3)						
	40	0.683	T	(16)	0.694	T	(16)			
1, 2-Quinone	25	0.787	T	(18)	0.784	T	(18)			
2-Methyl-1, 4-quinone (toluquinone)	0	0.660	T	(16)	0.682	T	(16)			
	18	0.6507	Q	(1)						
	25	0.6454	Q	(1)	0.658	T	(16)	0.655	T	(16)
	40	0.631	T	(16)	0.640	T	(16)			
2, 5-Dimethyl-1, 4-quinone (*p*-xyloquinone)	25	0.5900	T	(34)	0.601	T	(18)	0.600	T	(18)
2, 3, 5-Trimethyl-1, 4-quinone (cumoquinone)	25	0.527	T	(15)	0.529	T	(15)			
2-Methyl-5-isopropyl-1, 4-quinone (thymoquinone)	25	0.5875	T	(34)	0.590	T	(18)			
2, 3, 5, 6-Tetramethyl-1, 4-quinone (duroquinone)	25				0.466	T	(17)	0.467	T	(17)
Tetrahydro-1, 4-naphthoquinone	25	0.584	T	(15)	0.596	T	(15)	0.596	T	(15)
Monochloro-1, 4-quinone	25	0.7125	T	(34)	0.736	T	(17)	0.737	T	(17)
2, 3-Dichloro-1, 4-quinone	25	0.708	T	(17)				0.731†	T	(18)
2, 5-Dichloro-1, 4-quinone	25	0.720	T	(17)				0.738†	T	(18)
2, 6-Dichloro-1, 4-quinone	25	0.722	T	(17)				0.749	T	(17)
2, 3, 5-Trichloro-1, 4-quinone	25							0.732	T	(17)
2, 3, 5, 6-Tetrachloro-1, 4-quinone (chloranil)	25							0.696	T	(17)
Monobromo-1, 4-quinone	25	0.7151	T	(34)	0.735	T	(18)			
3, 4, 5, 6-Tetrabromo-1, 2-quinone	25	0.823	T	(18)	0.873	T	(18)			
3, 4, 5, 6-Tetrachloro-1, 2-quinone	25	0.827	T	(18)	0.876	T	(18)			
2, 5-Dimethoxy-1, 4-quinone	25							0.477	T	(18)
2, 6-Dimethoxy-1, 4-quinone	25	0.5139	T	(34)	0.528	T	(18)	0.530	T	(18)
2, 5-Diethoxy-1, 4-quinone	25	0.465	T	(18)	0.474	T	(18)			
Hydroxy-1, 4-quinone	25	0.596	T	(18)	0.601	T	(18)			
2, 5-Dihydroxy-1, 4-quinone	25	0.443	T	(18)	0.434	T	(18)			
1, 2-Naphthoquinone	25	0.547	T	(16)	0.577	T	(16)	0.581	T	(16)
1, 4-Naphthoquinone	25	0.4698	T	(34)	0.483	T	(18)	0.495	T	(18)
2-Chloro-1, 4-naphthoquinone	25							0.510	T	(18)
2, 3-Dichloro-1, 4-naphthoquinone	25							0.500	T	(18)
2-Bromo-1, 4-naphthoquinone	25							0.508	T	(18)
1, 4-Naphthoquinone-2-sulfonic acid	24	0.534	T	(16)	0.559	T	(16)	0.554	T	(16)
1, 2-Naphthoquinone-4-sulfonic acid	25	0.628	T	(18)	0.636	T	(18)			
1, 2-Naphthoquinone-4, 6-disulfonic acid	25	0.660	T	(18)	0.653	T	(18)			
2-Hydroxy-1, 4-naphthoquinone	25				0.357	T	(18)			
8-Hydroxy-1, 4-naphthoquinone	25				0.453	T	(18)			
2-Hydroxy-3-chloro-1, 4-naphthoquinone	25				0.352	T	(18)	0.350	T	(18)
2, 3-Diphenoxy-1, 4-naphthoquinone	25							0.457	T	(18)
Naphthopurpurin (2, 4, 8-trihydroxy-1, 4-naphthoquinone)	25				0.243*	T	(28)			
Naphthazarin (5, 8-dihydroxy-1, 4-naphthoquinone)	25				0.361*	T	(28)			
2, 6-Dihydroxy-1, 4-naphthoquinone	25				0.303*	T	(28)			
2-Allyl-3-hydroxy-1, 4-naphthoquinone	25				0.299*	T	(28)			
2-(α-Methylallyl)-3-hydroxy-1, 4-naphthoquinone	25				0.287*	T	(28)			
2-(γ-Methylallyl)-3-hydroxy-1, 4-naphthoquinone	25				0.295*	T	(28)			

TABLE 1.—(*Continued*)

A	*t*, °C	0.1*N* HCl (aqueous), volt	Method	Lit.	0.5*N* HCl,* 50 % C_2H_5OH, volt	Method	Lit.	0.5*N* HCl, 95 % C_2H_5OH, volt	Method	Lit.
Lapachol	25				0.287*	T	(28)			
Hydrolapachol	25				0.285*	T	(28)			
Chlorohydrolapachol	25				0.297*	T	(28)			
2-(β-Chloropropyl)-3-hydroxy-1, 4-naphthoquinone	25				0.304*	T	(28)			
Dibromohydrolapachol	25				0.291*†	T	(28)			
Hydroxyhydrolapachol	25				0.295*†	T	(28)			
Lomatiol	25				0.294*	T	(28)			
Hydroxyisolapachol	25				0.310*	T	(28)			
2-(β-Hydroxypropyl)-3-hydroxy-1, 4-naphthoquinone	25				0.308*	T	(28)			
Iso-β-lapachol	25				0.282*	T	(28)			
2-Benzyl-3-hydroxy-1, 4-naphthoquinone	25				0.296*	T	(28)			
1-Methyl-5, 6-benzo-3, 4-coumaranequinone	25				0.406*	T	(28)			
1, 2-Dimethyl-5, 6-benzo-3, 4-coumaranequinone	25				0.407*	T	(28)			
2-Methyl-7, 8-benzo-5, 6-chromanequinone	25				0.399*	T	(28)			
2-Phenyl-7, 8-benzo-5, 6-chromanequinone	25				0.413*	T	(28)			
β-Lapachone	25				0.403*	T	(28)			
Bromo-β-lapachone	25				0.427*	T	(28)			
Hydroxy-β-lapachone	25				0.411*	T	(28)			
Isopropylfurane-β-naphthoquinone	25				0.460*	T	(28)			
1-Methyl-4, 5-benzo-3, 6-coumaranequinone	25				0.375*	T	(28)			
2-Methyl-6, 7-benzo-5, 8-chromanequinone	25				0.307*	T	(28)			
α-Lapachone	25				0.304*	T	(28)			
Hydroxy-α-lapachone	25				0.320*	T	(28)			
Isopropylfurane-α-naphthoquinone	25				0.283*	T	(28)			
Isonaphthazarin (2, 3-dihydroxy-1, 4-naphthoquinone)	25				0.282*	T	(28)			
Isonaphthazarin monomethyl ether	25				0.329*	T	(28)			
Isonaphthazarin dimethyl ether	25				0.387*	T	(28)			
1-Methyl-5, 6-(β, β-naphtho)-3, 4-coumaranequinone	25				0.305*	T	(28)			
9, 10-Phenanthraquinone	25	0.442	T	(28)	0.458*	T	(28)	0.472	T	(18)
1-Methyl-7-isopropyl-9, 10-phenanthraquinone (retenequinone)	25							0.409	T	(18)
1, 2-Phenanthraquinone	25				0.651*	T	(30)			
3, 4-Phenanthraquinone	25				0.614*	T	(30)			
3, 4-Phenanthraquinone-1-sulfonic acid	25	0.664	T	(30)						
2-Hydroxy-1, 4-phenanthraquinone	25				0.410*	T	(30)			
3-Hydroxy-1, 4-phenanthraquinone	25				0.396*	T	(30)			
2-Methoxy-1, 4-phenanthraquinone	25				0.418*	T	(30)			
3-Methoxy-1, 4-phenanthraquinone	25				0.409*	T	(30)			
9, 10-Phenanthraquinone-3-sulfonic acid	25	0.472	T	(30)						
1, 2-Anthraquinone	25							0.493	T	(18)
1, 4-Anthraquinone	25				0.401*	T	(29)			
9, 10-Anthraquinone	25							0.157	T	(18)
Anthraquinone acids, *v.* Table 3										
2-Methyl-9, 10-anthraquinone	25							0.153	T	(18)
2-Chloromethyl-9, 10-anthraquinone	25							0.184†	T	(18)
1-Chloro-9, 10-anthraquinone	25							0.176	T	(18)
2-Chloro-9, 10-anthraquinone	25							0.203	T	(18)
2, 7-Dichloro-9, 10-anthraquinone	25							0.226†	T	(18)
9, 10-Anthraquinone-2-carboxylic acid	25							0.214	T	(18)
Methyl 9, 10-anthraquinone-2-carboxylate	25							0.225	T	(18)
Ethyl 9, 10-anthraquinone-2-carboxylate	25							0.224	T	(18)
2-Hydroxy-1, 4-anthraquinone	25				0.275*	T	(29)			
6, 7-Indazolequinone-4-sulfonic acid	25	0.620	T	(27)						
2-Phenylbenzotriazole-4, 5-quinone-7-sulfonic acid	25	0.644	T	(31)						
2-Phenyl-α, β-naphthotriazole-4, 5-quinone	25				0.470*	T	(31)			
3-Phenyl-α, β-naphthotriazole-4, 5-quinone	25				0.513*	T	(31)			
α, β-Naphthimidazole-4, 5-quinone	25				0.528*	T	(31)			
2-Methyl-3-phenyl-β, β-naphthimidazole-4, 9-quinone	25				0.320*	T	(31)			
1-(*p*-Tolyl)-β, β-naphthotriazole-4, 9-quinone	25				0.244*†	T	(31)			
Thionaphthenequinone	25	0.264	T	(31)						
Thiophanthraquinone	25				0.250*	T	(31)			
α, β-Naphthotriazole-4, 5-quinone	25	0.465	T	(31)						
α-Naphthoquinolinequinone	25	0.554	T	(31)						

A	AH_2	*t*, °C	0.1*N* HCl (aqueous)	Method	Lit.
Nitrosobenzene	Phenylhydroxylamine	25	0.605†	T, M	(20)
1-Nitroso-2-naphthol	1-Hydroxylamino-2-naphthol	25	0.523†	T	(20)
3, 3′-Diamino-4, 4′-dimethylazobenzene (azotoluidine)	3, 3′-Diamino-4, 4′-dimethylhydrazobenzene	18	0.375	M	(2)
		25	0.367	M	(2)
3, 3′-Diaminoazobenzene	3, 3′-Diaminohydrazobenzene	18	0.414	M	(2)
		37	0.402	M	(2)
Potassium azobenzene-4, 4′-disulfonate	Potassium hydrazobenzene-4, 4′-disulfonate	25	0.424	M	(22)

For the potentials of sulfonated dyestuffs, methylene blue and other dyes, *see* Table 3.

* Or 0.1*N* HCl and 0.2*N* LiCl.

TABLE 2

Emf of cell: [Pt] | H_2(1 atm. dry) | $H^+(c_H)$ | $H^+(c_H)$, A(satd.), B(satd.) | [Pt] +

Accuracy: ±1 in the third place, resp. 1–3 in the fourth place

Half-cell was saturated with	Solvent	°C	Volt	Lit.
1, 4-Quinone	0.1*N* aq. HCl	0	0.770	(17)
		5	0.7665	(36)
Quinhydrone of 1, 4-quinone		10	0.7620	(36)
		18	0.7562	(4)
		25	0.749	(17)
1, 4-Hydroquinone	0.1*N* aq. HCl	0	0.627	(17)
		12	0.6215	(36)
		18	0.6177	(4)
Quinhydrone of 1, 4-quinone		22	0.6150	(36)
		25	0.6123	(17, 33)
		32	0.6085	(36)
2-Methyl-1, 4-quinone	0.1*N* aq. HCl	0	0.677	(17)
Quinhydrone of 2-methyl-1, 4-quinone		25	0.661	(17)
2-Methyl-1, 4-hydroquinone	0.1*N* aq. HCl	0	0.610	(17)
Quinhydrone of 2-methyl-1, 4-quinone		25	0.584	(17)
2, 5-Dimethyl-1, 4-quinone (*p*-xyloquinone)	0.1*N* aq. HCl	0	0.600	(17)
2, 5-Dimethyl-1, 4-hydroquinone (*p*-xylohydroquinone)		25	0.582	(17)
2-Methyl-5-isopropyl-1, 4-quinone (thymoquinone)	0.1*N* aq. HCl	0	0.605	(17)
Quinhydrone of 2-methyl-5-isopropyl-1, 4-quinone		25	0.593	(17)
2-Methyl-5-isopropyl-1, 4-hydroquinone (thymohydroquinone)	0.1*N* aq. HCl	0	0.592	(17)
Quinhydrone of 2-methyl-5-isopropyl-1, 4-quinone		25	0.566	(17)
2, 3, 5, 6-Tetramethyl-1, 4-quinone (duroquinone)	50 % C_2H_5OH in 1*N* HCl	0	0.499	(17)
2, 3, 5, 6-Tetramethyl-1, 4-hydroquinone		25	0.481	(17)
Monochloro-1, 4-quinone	0.1*N* HCl satd. with NaCl	0	0.740	(17)
Quinhydrone of monochloro-1, 4-quinone		25	0.722	(17)
Monochloro-1, 4-hydroquinone	0.1*N* HCl satd. with NaCl	0	0.651	(17)
Quinhydrone of monochloro-1, 4-quinone		25	0.634	(17)
2, 6-Dichloro-1, 4-quinone	0.1*N* HCl satd. with NaCl	0	0.743	(17)
Quinhydrone of 2, 6-dichloro-1, 4-quinone		25	0.726	(17)
2, 6-Dichloro-1, 2,4-hydroquinone	0.1*N* HCl satd. with NaCl	0	0.690	(17)
Quinhydrone of 4 6-dichloro-1, 4-hydroquinone		25	0.669	(17)
2, 3-Dichloro-1, -quinone	0.1*N* HCl satd. with NaCl	0	0.692	(17)
2, 3-Dichloro-1, 4-hydroquinone		25	0.675	(17)
2, 5-Dichloro-1, 4-quinone	0.1*N* aq. HCl	0	0.710	(17)
2, 5-Dichloro-1, 4-hydroquinone		25	0.689	(17)
2, 3, 5-Trichloro-1, 4-quinone	0.1*N* aq. HCl	25	0.681	(17)
Quinhydrone of 2, 3, 5-trichloro-1, 4-quinone				
2, 3, 5-Trichloro-1, 4-hydroquinone	0.1*N* aq. HCl	25	0.661	(17)
Quinhydrone of 2, 3, 5-trichloro-1, 4-quinone				
2, 3, 5-Trichloro-1, 4-quinone	0.1*N* aq. HCl	0	0.690	(17)
2, 3, 5-Trichloro-1, 4-hydroquinone		25	0.670	(17)
2, 3, 5, 6-Tetrachloro-1, 4-quinone	0.1*N* aq. HCl	0	0.683	(17)
2, 3, 5, 6-Tetrachloro-1, 4-hydroquinone		25	0.664	(17)
Alloxantin	0.1*N* H_2SO_4	18	0.3699	(5)
		25	0.3664	(5)
N, *N*-Tetramethylalloxantin	0.1*N* H_2SO_4	18	0.3657	(5)

TABLE 3

Emf of the cell: [Pt] | H_2(1 atm.) | *N* H^+ | KCl(satd.) | $H^+(c_H)$, $A(c_1)$, $AH_x(c_2)$ | Pt +

As computed from measurements against the calomel half cell

The variation in emf as a function of $[H^+] = c_H$ is given by one of several types of equations listed below. The value of $[H^+]$ was determined from the emf of the cell

[Pt] | H_2(1 atm.) | $H^+(c_H)$ | KCl(satd.) | HgCl | Hg

Liquid junction potentials were neglected in determining both the value of $[H^+]$ and that of the oxidation reduction cell involving the "normal hydrogen electrode." The ultimate working standard was the hydrogen electrode in *N*/20 potassium acid phthalate to which the value 0.2386 volt at 30° referred to the "normal hydrogen electrode" was assigned. The type of equation and the experimentally determined constants are listed in the tables as well as the range of $[H^+]$ in which the measurements were made. The concentration of organic material was 0.001–0.005 molar. The results are significant within 1 or 2 mv except with the anthraquinone derivatives where the error may be 3–5 mv.

TABLE 3.—(*Continued*)

(A) $E_0 - \frac{RT}{2F}\log_e\frac{c_2}{c_1} + \frac{RT}{2F}\log_e[K_1[H^+] + [H^+]^2]$

(B) $E_0 - \frac{RT}{2F}\log_e\frac{c_2}{c_1} + \frac{RT}{2F}\log_e[K_1K_2 + K_1[H^+] + [H^+]^2]$

(C) $E_0 - \frac{RT}{2F}\log_e\frac{c_2}{c_1} + \frac{RT}{2F}\log_e[K_rK_2[H^+] + K_r[H^+]^2 + [H^+]^3] - \frac{RT}{2F}\log_e(K_0 + [H^+])$

(D) $E_0 - \frac{RT}{2F}\log_e\frac{c_2}{c_1} - \frac{RT}{2F}\log_e\left[\frac{K_{obs.}[H^+] + K_w}{K_{r2}K_{r3}[H^+]^2 + K_{r3}[H^+]^3 + [H^+]^4}\right]$

where E_0 is given in volt, $[H^+]$ determined as stated above, K_1 and K_2 the acid dissociation constants of phenolic groups formed by the reduction, and K_r and K_0 the acid dissociation constants in the reduced and oxidized compounds, respectively, of an acidic group common to both.

Oxidized compound A	Reduced compound AH_x	Type of equation	°C	pH range investigated	Constants					Method	Lit.
					E_0, volt	K_1	K_2	K_0	K_r		
Indigo-5-sulfonic-acid	Leucoindigo-5-sulfonic acid	A	30	1.1–12.6	0.262	1.6×10^{-8}				M	(38)
Indigo-5, 5′-disulfonic acid	Leucoindigo-5, 5′-disulfonic acid	A	30	1.1–12.6	0.291	4.9×10^{-8}				M	(38)
Indigo-5, 5′, 7-trisulfonic acid	Leucoindigo-5, 5′, 7-trisulfonic acid	A	30	1.1–12.6	0.332	7.7×10^{-8}				M	(38)
Indigo-5, 5′, 7, 7′-tetrasulfonic acid.	Leucoindigo-5, 5′, 7, 7′-tetrasulfonic acid	A	30	1.1–12.6	0.365	11.2×10^{-8}				M	(38)
1-Naphthol-4-indophenol-2-sulfonic acid	Leuco-1-naphtholindophenol-2-sulfonic acid	C	30	1.1–12.6	0.544		2.0×10^{-11}	2.1×10^{-9}	8.0×10^{-10}	M, T	(8)
Phenol-4-indophenol	Leucophenolindophenol	C	30	6.2–12.3	0.649		2.3×10^{-11}	8.0×10^{-9}	3.6×10^{-10}	M, T	(11)
o-Cresol-4-indophenol	Leuco-*o*-cresolindophenol	C	30	6.3–12.3	0.616		1.3×10^{-11}	4.2×10^{-9}	3.0×10^{-10}	M, T	(11)
m-Cresol-4-indophenol	Leuco-*m*-cresolindophenol	C	30	6.3–12.3	0.632		2.2×10^{-11}	2.8×10^{-9}	2.7×10^{-10}	M, T	(11)
Thymol-4-indophenol	Leucothymolindophenol	C	30	5.7–12.3	0.592		1.5×10^{-11}	1.6×10^{-9}	1.4×10^{-10}	M, T	(11)
Carvacrol-4-indophenol	Leucocarvacrolindophenol	C	30	5.7–12.3	0.593		1.8×10^{-11}	1.4×10^{-9}	1.4×10^{-10}	M, T	(11)
o-Bromophenol-4-indophenol	Leuco-*o*-bromophenolindophenol	C	30	5.8–11.7	0.659		5.8×10^{-11}	7.8×10^{-8}	3.0×10^{-9}	M, T	(11)
m-Bromophenol-4-indophenol	Leuco-*m*-bromophenolindophenol	C	30	5.2–11.7	0.670		5.0×10^{-11}	1.5×10^{-8}	1.1×10^{-9}	M, T	(11)
o-Chlorophenol-4-indophenol	Leuco-*o*-chlorophenolindophenol	C	30	4.0–12.3	0.663		5.0×10^{-11}	1.0×10^{-7}	3.6×10^{-9}	M, T	(11)
o-Cresolindo-2, 6-dichlorophenol.	Leuco-*o*-cresolindo-2, 6-dichlorophenol	C	30	5.7–11.4	0.639		3.7×10^{-11}	3.2×10^{-6}	8×10^{-8}	M, T	(32)
Phenolindo-2, 6-dichlorophenol.	Leucophenol-indo-2, 6-dichlorophenol	C	30	6.3–11.4	0.668		7.4×10^{-11}	2×10^{-6}	1×10^{-7}	M, T	(32)
o-Chlorophenolindo-2, 6-dichlorophenol.	Leuco-*o*-chlorophenolindo-2, 6-dichlorophenol	C	30	5.7–11.4	0.668		1.8×10^{-9}	1.6×10^{-6}	9×10^{-8}	M, T	(32)
1-Naphthol-2-sulfonate-indo-2, 6-dichlorophenol	Leuco-compound	C	30	5.0–11.4	0.563		4.787×10^{-10}	7.245×10^{-7}	3.549×10^{-8}	M, T	(32)
m-Cresol-2-indophenol	Leuco-*m*-cresol-2-indophenol	C	30	5.7–12.3	0.647		2.0×10^{-11}	4.2×10^{-9}	4.5×10^{-10}	M, T	(12)
Phenol-4-indo-2′, 6′-dibromophenol.	Leucophenol-4-indo-2′, 6′-dibromophenol	C	30	7.0–12.3	0.668		8.9×10^{-11}	2×10^{-6}	1×10^{-7}	M, T	(12)
9, 10-Anthraquinone-1-sulfonic acid.	9, 10-Anthrahydroquinone-1-sulfonic acid	A	0	3 and 4.3	0.209	(?)					
			25	1.2–13.7	0.195	0.4×10^{-8}				T	(19)
			40	3 and 4.3	0.186	(?)					
9, 10-Anthraquinone-1, 5-disulfonic acid.	9, 10-Anthrahydroquinone-1, 5-disulfonic acid	A	0	3, 4 and 6	0.251	(?)				T	(16)
			25	1.2–13.7	0.239	3×10^{-12}				T	(19)
			40	3, 4 and 6	0.230	(?)				T	(16)
9, 10-Anthraquinone-1, 8-disulfonic acid.	9, 10-Anthrahydroquinone-1, 8-disulfonic acid	A	25	1.2–13.7	0.206	0.7×10^{-8}				T	(19)
9, 10-Anthraquinone-2-sulfonic acid.	9, 10-Anthrahydroquinone-2-sulfonic acid	B	0	3, 6 and 7	0.198	(?)				T	(16)
			25	1.2–13.7	0.187	1×10^{-8}	5×10^{-12}			T	(19)
			40	3, 6 and 7	0.172	(?)				T	(16)
9, 10-Anthraquinone-2, 6-disulfonic acid.	9, 10-Anthrahydroquinone-2, 6-disulfonic acid	B	0	3 and 7	0.240	(?)				T	(16)
			25	1.2–13.7	0.228	0.8×10^{-8}	3×10^{-11}			T	(19)
			40	3 and 7	0.210	(?)				T	(16)
9, 10-Anthraquinone-2, 7-disulfonic acid.	9, 10-Anthrahydroquinone-2, 7-disulfonic acid	B	0	3 and 7	0.243	(?)				T	(16)
			25	1.2–13.7	0.229	2×10^{-8}	3×10^{-11}			T	(19)
			40	3 and 7	0.215	(?)				T	(16)
1, 2-Anthraquinone-4-sulfonic acid.	1, 2-Anthrahydroquinone-4-sulfonic acid		25	0.76	0.530					T	(29)

Compounds with which equation D must be employed.

		Type of equation	°C	pH range investigated	E_0'*	K_{r2}	K_{r3}	$K_{obs.}$	K_r	Method	Lit.
Methylene blue	Methylene white	D	30	1–12	0.532	1.4×10^{-6}	3×10^{-5}	negligible		T	(9)
Lauth's violet	Leuco-compound	D	30	1–12.6	0.536	5×10^{-6}	4.2×10^{-5}	1.88×10^{-3}		T	(9)

* $E_0' = E_0 - \frac{RT}{2F}\log_e\frac{c_2}{c_1}$.

NOTE.—Concentrations 0.0001 to 0.00006*N*.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Biilmann, *14*, **15**: 109; 21. (2) Biilmann and Blom, *4*, **125**: 1719; 24. (3) Biilmann and Krarup, *4*, **125**: 1954; 24. (4) Biilmann and Lund, *14*, **16**: 321; 21. (5) Biilmann and Lund, *14*, **19**: 137; 23. (6) Clark, *231*, **38**: 443; 23. (7) Clark and Cohen, *231*, **38**: 666; 23. (8) Clark and Cohen, *231*, **38**: 933; 23. (9) Clark, Cohen and Gibbs, *231*, **40**: 1131; 25. (10) Clark, Cohen and Gibbs, *231 Suppl.*, **No. 54**; 26. (11) Cohen, Gibbs and Clark, *231*, **39**: 381; 24. (12) Cohen, Gibbs and Clark, *231*, **39**: 804; 24. (13) Conant, *1*, **49**: 293; 27. (14) Conant and Cutter, *50*, **28**: 1096; 24. (15) Conant and Dunkle, *0*. (16) Conant and Fieser, *1*, **44**: 2480; 22. (17) Conant and Fieser, *1*, **45**: 2194; 23. (18) Conant and Fieser, *1*, **46**: 1858; 24. (19) Conant, Kahn, Fieser and Kurtz, *1*, **44**: 1382; 22. (20) Conant and Lutz, *1*, **45**: 1047; 23. (21) Conant and Lutz, *1*, **46**: 1254; 24. (22) Conant and Pratt, *1*, **48**: 2468; 26. (23) Conant and Pratt, *1*, **48**: 3178; 26. (24) Conant and Scott, *141*, **76**: 207; 28. (25) Conant, Small and Taylor, *1*, **47**: 1959; 25. (26) Ebert, *25*, **58**: 175; 25. (27) Fieser, *1*, **48**: 1097; 26. (28) Fieser, *1*, **50**: 439; 28. (29) Fieser, *1*, **50**: 465; 28. (30) Fieser, Bryn Mawr College, *0*. (31) Fieser and Ames, *1*, **49**: 2604; 27. (32) Gibbs, Cohen and Cannan, *231*, **40**: 649; 25. (33) Granger and Nelson, *1*, **43**: 1401; 21. (34) LaMer and Baker, *1*, **44**: 1954; 22. (35) Phillips, Clark and Cohen, *231 Suppl.*, **No. 61**; 27. (36) Schreiner, *7*, **117**: 57; 25. (37) Sörensen, Sörensen and Linderstrom-Lang, *14*, **16**: 283; 21. (38) Sullivan, Cohen and Clark, *231*, **38**: 1669; 23.

LIQUID JUNCTION POTENTIALS

Duncan A. MacInnes

The emf (E_L), of liquid junctions, ||, in galvanic cells may be obtained for four types of junction: (1) $M_1A(C_1)||M_2A(C_1)$ or $MA_1(C_1)||MA_2(C_1)$; (2) $M_1A(C)||M_2A(Cx) + M_1A[C(1-x)]$; (3) $MA(C_1)||MA(C_2)$; and (4) saturated KCl||MA. M and A represent univalent cations and anions respectively; C_1 and C_2, concentrations. For type (1), $E_L = \frac{RT}{F} \log_e \frac{\Lambda_1}{\Lambda_2}$ (approximately), where Λ is the equivalent conductance at the (single) concentration involved (13, 15). Type (2) may be computed from the relation: $E_L = RT/F.\ \log_e [(1-t_2) - x(t_1 - t_2)]/(1-t_1)$, ($t_1$ and t_2 are the transference numbers of the ion constituents M_1 and M_2, and x is a factor less than unity) (23). For type (3) $E_L = \frac{(1-2t)RT}{F} \log_e \frac{a_1}{a_2}$, if the ions have the same activities, a, at each concentration (t is the transference number) (14). Type (4) junctions can be regarded as *constant*, for most purposes, for concentration changes of MA up to $0.1N$ (3, 8, 17).

Cells	t, °C	Emf, millivolt	Literature and remarks
+Au | $K_4Fe(CN)_6$ KCl(0.2N) || KAc(0.2N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$ |	25	6.9	(13)
+Au | $K_4Fe(CN)_6$ KCl(0.1N) || KAc(0.1N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$ |	25	6.9	Equal small amounts of ferro- and ferri-cyanides in both half cells.
−Au | $K_4Fe(CN)_6$ KCl(0.2N) || KOH(0.2N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$ |	25	16.1	Potentials closely that of liquid junction.
−Au | $K_4Fe(CN)_6$ KCl(0.1N) || KOH(0.1N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$ |	25	15.7	
+Au | $K_4Fe(CN)_6$ KCl(0.2N) || KBr(0.2N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$	25	0.4	
−Au | $K_4Fe(CN)_6$ NaCl(0.2N) || NaOH(0.1N)$K_4Fe(CN)_6$ | Au ..... | $K_3Fe(CN)_6$ $K_3Fe(CN)_6$	25	18.1	
−Ag| AgCl, HCl(0.1N) || KCl(0.1N)AgCl| Ag	25	27.8	(12)
−Ag| AgCl, HCl(0.01N) || KCl(0.01N)AgCl| Ag	25	27.2	
Ag| AgCl, $M_1Cl(0.1N)$ || $M_2Cl(0.1N)$, AgCl| Ag	25	$E_1 - E_2$	(15)
Values of E, LiCl, 35.65; KCl, 26.78; HCl, 0.00; NaCl, 33.08; NH_4Cl, 28.78, millivolt.			Flowing junctions (11). Potential in millivolts obtained by subtracting figure given for M_2Cl from value for M_1Cl, the resulting algebraic sign is the sign of the potential of the left-hand electrode. If the activities of the chloride ion are the same, at the concentration given, the potential thus computed is that of the liquid junction.
Ag| AgCl, $M_1Cl(0.01N)$ || $M_2Cl(0.01N)$, AgCl| Ag	25	$E_1 - E_2$	
Values of E, LiCl, 33.82; KCl, 25.62; HCl, 0.00; NaCl, 31.19; NH_4Cl, 26.93; CsCl, 26.02, millivolt.			
−Ag| AgCl, HCl(0.1N) || NaCl(0.02346N) HCl(0.07654N), AgCl| Ag	25	4.75	(24)
−Ag| AgCl, HCl(0.1N) || NaCl(0.05050N) HCl(0.04950N), AgCl| Ag	25	11.85	Type 2 (*see* above). Flowing junctions. Measured potentials close to liquid junction potentials.
−Ag| AgCl, HCl(0.1N) || NaCl(0.06142N) HCl(0.03858N), AgCl| Ag	25	15.12	
−Ag| AgCl, HCl(0.1N) || NaCl(0.07518N) HCl(0.02482N), AgCl| Ag	25	20.17	
−Ag| AgCl, HCl(0.1N) || NaCl(0.08931N) HCl(0.01069N), AgCl| Ag	25	26.80	
−Ag| AgCl, HCl(0.1N) || NaCl(0.09400N) HCl(0.00600N), AgCl| Ag	25	29.41	

Potentials at junctions of aqueous solutions of electrolytes with solutions in immiscible solvents, *see* (1, 2, 18, 19, 20, 21, 22).
Potentials at membranes, *see* (5, 6, 7).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Baur and Kronmann, *7*, **92**: 81; 16. (2) Beutner, *1*, **35**: 344; 13. **36**: 2041, 2045; 14. *7*, **87**: 385; 14. (3) Bjerrum, *7*, **53**: 428; 05. (4) Cumming and Gilchrist, *83*, **9**: 174; 13. (5) Donnan and Allmand, *4*, **105**: 1941; 14. (6) Donnan and Garner, *4*, **115**: 1313; 19. (7) Donnan and Green, *5*, **90**: 450; 14. (8) Fales and Mudge, *1*, **42**: 2434; 20. (9) Fales and Vosburgh, *1*, **40**: 1291; 18.

(10) Henderson, *7*, **59**: 118; 07. **63**: 325; 08. (11) Lamb and Larson, *1*, **42**: 229; 20. (12) Lewis. Brighton and Sebastian, *1*, **39**: 2245; 17. (13) Lewis and Sargent, *1*, **31**: 363; 09. (14) MacInnes, *1*, **37**: 2301; 15. (15) MacInnes and Yeh, *1*, **43**: 2563; 21. (16) Planck, *8*, **40**: 561; 90. (17) Scatchard, *1*, **47**: 696; 25. (18) Voznesenskii, *7*, **115**: 405; 25. (19) Voznesenskii and Astachov, *7*, **118**: 295; 25.

(20) Voznesenskii and Astachov, *7*, **128**: 362; 27. (21) Voznesenskii, Astachov and Chmutov, *7*, **121**: 143; 26. (22) Voznesenskii and Chmutov, *53*, **57**: 343; 25 (23) MacInnes, *1*, **48**: 2831; 26. (24) Smith, *546*, **2**: 1137; 29.

OVERVOLTAGE

MAX KNOBEL

Overvoltage is the potential necessary to discharge the ion in question in excess of that necessary for reversible discharge, the reversible and irreversible electrodes being under the same condition of temperature, pressure, electrolyte, etc.

The actual magnitude of any overvoltage value cannot be specified precisely because of uncontrollable variability. The usual reproducibility is not better than 0.05 volt.

All values given are determined by the "direct" method, that is, while the polarizing current is flowing. For references on the comparative value of commutator and direct method, *see* (2, 3, 5, 9, 10, 14).

EFFECT OF CURRENT DENSITY ON OVERVOLTAGE (7)

Smooth Electrodes unless Otherwise Designated.—Electrolyte for hydrogen overvoltages is $2N$ H_2SO_4; for halogen overvoltages, a saturated solution of the sodium or potassium halide with the halogen; for oxygen overvoltages, $1N$ KOH. The hydrogen overvoltages are most reliable and by careful duplication of conditions are reproducible to 0.1 volt or better. The halogen overvoltages are the least reliable due to coatings on the electrode.

For other references on the effect of current density, *see* the above article. It is impracticable to attempt to average the results of different investigators on account of the sensitivity of overvoltage to many conditions of measurement.

HYDROGEN OVERVOLTAGES AT 25°C

Milliamp per cm²	Overvoltage in volt						
	Au	Cd	Cu	Platinized Pt	Smooth Pt	Al	Graphite
0		0.466		0.000			0.0022
0.1	0.122	0.651	0.351	0.0034		0.499	0.3166
1	0.241	0.981	0.479	0.0154	0.024	0.565	0.5995
2				0.0208	0.034	0.625	0.6520
5	0.332	1.086	0.548	0.0272	0.051	0.745	0.7250
10	0.390	1.134	0.584	0.0300	0.068	0.826	0.7788
50	0.507	1.211		0.0376	0.186	0.968	0.9032
100	0.588	1.216	0.801	0.0405	0.288	0.996	0.9774
200	0.668	1.228	0.988	0.0420	0.355	1.176	1.0794
500	0.770	1.246	1.186	0.0448	0.573	1.237	1.1710
1000	0.798	1.254	1.254	0.0483	0.676	1.286	1.2200
1500	0.807	1.257	1.269	0.0495	0.768	1.292	1.2208

Milliamp per cm²	Overvoltage in volt					
	Ag	Sn	Fe electrode	Brass	Monel metal	Duriron
0		0.2411	0.2026			0.1680
0.1	0.2981	0.3995	0.2183	0.3832	0.1911	0.1710
1	0.4751	0.8561	0.4036	0.4967	0.2754	0.1970
2	0.5787	0.9469	0.4474	0.5346	0.3022	0.2136
5	0.6922	1.0258	0.5024	0.5960	0.3387	0.2443

HYDROGEN OVERVOLTAGES.—(*Continued*)

Milliamp per cm²	Overvoltage in volt					
	Ag	Sn	Fe electrode	Brass	Monel metal	Duriron
10	0.7618	1.0767	0.5571	0.6459	0.3832	0.2856
50	0.8300	1.1851	0.7000	0.8011	0.5345	0.5096
100	0.8749	1.2230	0.8184	0.9104	0.6244	0.6129
200	0.9379	1.2342	0.9854	1.1088	0.7108	0.7240
500	1.0300	1.2380	1.2561	1.2318	0.8619	0.8591
1000	1.0890	1.2306	1.2915	1.2544	1.0716	1.0205
1500	1.0841	1.2286	1.2908	1.2491	1.2095	1.1400

Milliamp per cm²	Overvoltage in volt				
	Zn	Carbon	Bi	Ni	Pb
1	0.716		0.78	0.563	0.52
2	0.726			0.633	
5	0.726	0.64	0.98	0.705	1.060
10	0.746	0.70	1.05	0.747	1.090
50	0.926	0.82	1.15	0.890	1.168
100	1.064	0.89	1.14	1.048	1.179
300	1.168	1.04	1.20	1.130	1.217
500	1.201	1.10	1.21	1.208	1.235
1000	1.229	1.17	1.23	1.241	1.262
1500	1.243	1.23	1.29	1.254	1.290

Milliamp per cm²	Overvoltage Hg	Milliamp per cm²	Overvoltage Te	Milliamp per cm²	Overvoltage Pd
0.00	0.2805	0.416	0.0504	0.227	0.0546
0.0769	0.5562	0.832	0.3505	1.135	0.1392
0.769	0.8488	1.667	0.4162	2.27	0.1820
1.54	0.9295	4.16	0.4405	4.54	0.2349
3.87	1.0060	8.32	0.4300	11.35	0.3165
7.69	1.0361	41.6	0.4705	22.7	0.4034
38.7	1.0634	83.2	0.4733	113.5	0.7205
76.9	1.0665	166.7	0.4986	227	0.8607
154	1.0751	416	0.5370	454	0.9521
387	1.1053	832	0.5940	1135	1.0513
769	1.108	1250	0.6590	2270	1.1168
1153	1.126			3400	1.1570

CHLORINE OVERVOLTAGES AT 25°C

Platinized Pt		Smooth Pt		Graphite	
Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage
1.1	0.0060	1.1	0.008	40	0.186
5.7	0.0140	5.7	0.0199	70	0.193
14.5	0.0180	11.4	0.0299	100	0.251
21.7	0.0190	22.8	0.0378	200	0.298

CHLORINE OVERVOLTAGES.—(*Continued*)

Platinized Pt		Smooth Pt		Graphite	
Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage
38.8	0.0210	43.0	0.0457	500	0.417
60	0.024	100	0.0540	740	0.466
100	0.026	200	0.0870	980	0.489
200	0.035	500	0.161	1131	0.535
520	0.050	750	0.212		
1340	0.089	1000	0.236		
1490	0.103	1350	0.263		

BROMINE OVERVOLTAGES AT 25°C

Platinized platinum		Smooth platinum		Graphite	
Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage
10	0.002	20	0.002	10	0.002
30	0.005	30	0.004	30	0.008
50	0.007	50	0.006	50	0.016
100	0.012	230	0.033	100	0.027
200	0.025	300	0.057	200	0.054
300	0.041	360	0.113	300	0.081
420	0.056	400	0.156	390	0.108
500	0.069	420	0.164	550	0.163
590	0.082	440	0.178	740	0.218
760	0.130	520	0.266	840	0.253
940	0.202	720	0.379	990	0.329
				1110	0.356
				1210	0.400

IODINE OVERVOLTAGES AT 25°C

Platinized platinum		Smooth platinum		Graphite	
Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage	Milliamp per cm²	Overvoltage
10	0.006	12.3	0.0039	1.2	0.002
20	0.012	23	0.0070	5.7	0.007
40	0.022	50	0.0127	11.7	0.0139
110	0.032	90	0.0216	19.7	0.0239
220	0.050	130	0.0353	34.8	0.0348
400	0.070	200	0.0510	50	0.0538
710	0.118	310	0.0744	100	0.0974
810	0.130	520	0.120	200	0.175
1000	0.196	690	0.150	400	0.315
1300	0.216	1030	0.220	590	0.451
1460	0.266	1160	0.245	840	0.645
		1330	0.277		
		1500	0.292		

OXYGEN OVERVOLTAGES AT 25°C

Milliamp per cm²	Overvoltage in volt			
	Soft graphite	Au	Cu	Ag
1	0.525	0.673	0.422	0.580
5	0.705	0.927	0.546	0.674
10	0.896	0.963	0.580	0.729
20	0.963	0.996	0.605	0.813
50		1.064	0.637	0.912
100	1.091	1.244	0.660	0.984
200	1.142		0.687	1.038
500	1.186	1.527	0.735	1.080
1000	1.240	1.63	0.793	1.131
1500	1.282	1.68	0.836	1.14

OXYGEN OVERVOLTAGES.—(*Continued*)

Milliamp per cm²	Overvoltage in volt			
	Smooth Pt	Platinized Pt	Smooth Ni	Spongy Ni
1	0.721	0.398	0.353	0.414
5	0.80	0.480	0.461	0.511
10	0.85	0.521	0.519	0.563
20	0.92	0.561		
50	1.16	0.605	0.670	0.653
100	1.28	0.638	0.726	0.687
200	1.34		0.775	0.714
500	1.43	0.705	0.821	0.740
1000	1.49	0.766	0.853	0.762
1500	1.38	0.786	0.871	0.759

EFFECT OF TEMPERATURE ON OVERVOLTAGE

Average temperature coefficient of hydrogen overvoltage on smooth electrodes in $2N$ H_2SO_4 for temperature range 0 to 75°C (8); *cf.* (11, 12, 13).

Electrode	Current density, amp/cm²	dE/dT, mv(millivolt)/°C
Silver	0.40	2.0
	0.10	2.4
	0.01	2.5
Copper	0.40	2.4
	0.10	2.6
	0.01	3.1
Nickel	0.10	2.4
	0.01	2.6
Lead	0.40	1.8
	0.10	2.0
	0.05	1.6

For other articles each containing a few measurements, *see* (10.5, 11, 12, 13).

EFFECT OF PRESSURE ON OVERVOLTAGE (1)

Hydrogen overvoltage increases with reduction in pressure by the same amount that the reversible hydrogen electrode potential increases, *i.e.*, potential of polarized cathode measured against an electrode such as the Hg: Hg_2SO_4 which does not change with pressure, is constant. For Hg, Ni, and Pb, very low current density, pressure range 20 to 750 mm, 20°C. Confirmed by Knobel (6) for smooth lead, copper and nickel, and for platinized platinum each at current densities of 0.01, 0.1, and 1.0 amp per cm², and for pressure range 22 mm to 760 mm Hg, 25°C.

Divergent results (4).

Oxygen overvoltage, 100 atm. (9) decrease of 0.02 volt from value at 1 atm.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bircher and Harkins, *1*, **45**: 2890; 23. (2) Dunnill, *4*, **119**: 1081; 21. (3) Glasstone, *58*, **111**: 775; 23. (4) Goodwin and Wilson, *78*, **40**: 173; 21. (5) Knobel, *1*, **46**: 2613; 24. (6) Knobel, *1*, **46**: 2751; 24. (7) Knobel, Caplan and Eiseman, *78*, **43**: 55; 23. (8) Knobel and Joy, *78*, **44**: 443; 23. (9) Newbery, *4*, **105**: 2419; 14.
(10) Newbery, *83*, **15 I**: 126; 19. (10.5) Onoda, *93*, **162**: 57; 27. **165**: 79; 27. (11) Pring and Curzon, *83*, **7**: 237; 12. (12) Rideal, *1*, **42**: 94; 20. (13) Tafel, *7*, **50**: 641; 05. (14) Tartar and Keyes, *1*, **44**: 557; 22.

ELECTRICAL AND OPTICAL PROPERTIES OF SILICA

ROBERT B. SOSMAN

Dielectric Constant (12, 16, 27, 28.1, 38, 67, 76, 79, 81, 85)

	Most probable value	Limits between which the true value certainly lies
Quartz, axis ∥ to direction of field	4.6	4.5 and 5.0
Quartz, axis ⊥ to direction of field	4.5	4.2 and 4.7
Difference (∥) − (⊥)	+0.1	+0.1 and +0.4
Vitreous silica	3.75	3.2 and 3.9

Electrical Resistivity

Unit, ohm-cm (1, 7, 12, 16, 22, 26, 35, 39, 67, 68, 84, 86, 90)

t, °C	Quartz		Vitreous silica†			
	∥ to axis*	⊥ to axis	t, °C	ohm-cm	t, °C	ohm-cm
20	0.1×10^{15}	20×10^{15}	20	10×10^{18}	700	10×10^{6}
100	0.8×10^{12}		100	1×10^{18}	800	4×10^{6}
200	70×10^{9}		200	10×10^{15}	900	2×10^{6}
300	60×10^{6}		300	0.2×10^{12}	1000	1×10^{6}
1000	50×10^{3}	100×10^{3}	400	5×10^{9}	1100	0.7×10^{6}
1300	5×10^{3}	10×10^{3}	500	0.3×10^{9}	1200	0.5×10^{6}
			600	60×10^{6}	1300	0.4×10^{6}

* This is natural quartz, whose axial conductance is due mainly to impurities; the true axial resistivity of pure quartz is not known.

† *Cf.* Seemann (*2*, **31**: 119; 28), who finds lower values

Piezoelectric Constants of Quartz (14, 15, 18, 33, 63, 69, 73, 74)

Pressure in baryes (dynes per cm²); charge in absolute electrostatic units per cm²

d_{11} (principal coefficient) ..... -69×10^{-9}

d_{14} ..... $+17\times10^{-9}$

See also p. 211.

Magnetic Susceptibility (13, 41, 89, 94)

Quartz *in vacuo*, at 20°C

Volume-susceptibility, $10^{6}\kappa$		Mass-susceptibility, $10^{6}\kappa_1$	
∥ to axis	⊥ to axis	∥ to axis	⊥ to axis
−1.21	−1.20	−0.457	−0.452

Optical Constants (5, 10, 20, 25, 28, 50, 55, 64, 78, 91, 93)

Room temperature

	Low-quartz	Low-tridymite	Low-cristobalite	Vitreous silica
Indices of refraction for sodium light $n\alpha$	1.544 (n_ω)	1.469	1.484	
$n\beta$		1.47	Near 1.487	
$n\gamma$	1.553 (n_ϵ)	1.473	1.487	1.459 (n)
Birefringence for sodium light ($n\gamma - n\alpha$)	0.009	0.004	0.003 or higher	0
Constringence, ν	For o, 69.9 / For e, 68.7			67.6
Optical character	Positive	Positive	Negative	
Optical orientation	$c = n\gamma$			
Optical character of elongation	Positive	Negative		
Optic axial angle, $2V\gamma$	0	35 to 43°	>90°	
Apparent optic axial angle, $2E\gamma$	0	56 to 66°	>90°	
Optical rotatory power, α_D	21.72° per mm			0.000°

Refractive Index

At 18°, in Air at Same Temperature (6, 9, 19, 24, 29, 30, 34, 47, 48, 49, 51, 55, 58, 60, 61, 70, 71, 76, 87, 92)

Radiating element	Wavelength in air at 15°, mμ	N_ω, quartz	N_ϵ, quartz	N, vitreous
Al	185.467	1.67578	1.68997	1.57436
Al	193.583	1.65999	1.67343	1.55999
Au	200.06	1.64927	1.66227	
Zn	202.55	1.64557	1.65842	1.54727
Au	204.448	1.64288	1.65562	
Au	211.07	1.63432	1.64671	
Cd	214.439	1.63039	1.64262	1.53386
Cd	219.462	1.62497	1.63698	1.52907
Cd	226.503	1.61818	1.62992	1.52308
Cd	231.288	1.61401	1.62559	1.51941
Au	242.796	1.60525	1.61650	
Au	250.329	1.60032	1.61139	1.50745
Cd	257.304	1.59622	1.60714	1.50379
Al	263.155	1.59309	1.60389	
Cd	274.867	1.58752	1.59813	1.49617
Au	291.358	1.58098	1.59136	
Sn	303.412	1.576955	1.58720	1.48594
Au	312.279	1.57433	1.584485	
Cd	325.253	1.570915	1.58095	
Cd	340.365	1.56747	1.577385	1.47867
Al	358.68	1.563915	1.573705	
Ca	396.848	1.55813	1.56772	1.47061
Hg	404.656	1.557156	1.56671	1.46968
H	410.174	1.556502	1.566031	
H	434.047	1.553963	1.563405	1.46690
Hg	435.834	1.553790	1.563225	1.46675
Cd	467.815	1.551027	1.560368	1.46435
Cd	479.991	1.550118	1.559428	1.46355
H (solar line "F")	486.133	1.549683	1.558979	1.46318
Cd	508.582	1.548229	1.557475	1.46191
Mg (solar line "b_1")	518.362	1.547651	1.556877	
Cd	533.85	1.546799	1.555996	1.46067
Hg	546.072	1.546174	1.555350	1.46013
Hg	579.066	1.544667	1.553791	
He	587.563	1.544316	1.553428	
Na (mean)	589.29	1.544246	1.553355	1.45845
Au	627.82	1.542819	1.551880	
Cd	643.847	1.542288	1.551332	1.45674
H (solar line "C")	656.278	1.541899	1.550929	1.45640
He	667.815	1.541553	1.550573	
Li	670.786	1.541466	1.550483	
He	706.520	1.540488	1.549472	1.45517
He	728.135	1.539948	1.548913	
K	766.494	1.539071	1.548005	
Rb	794.763	1.538478	1.547392	1.45340
O	844.67	1.537525	1.54640	
	1000.00	1.53503	1.54381	
Hg	1014.06	1.53483	1.54360	
He	1083.03	1.53387	1.54260	
	1200.00	1.53232	1.54098	
	1300.00	1.53102	1.53962	
	1400.00	1.52972	1.53826	

Refractive Index.—(*Continued*)

Radiating element	Wave-length in air at 15°, mμ	N_ω, quartz	N_ϵ, quartz	N, vitreous
Hg	1529.61	1.52800	1.53646	
	1600.00	1.52703	1.53545	
	1800.00	1.52413	1.53242	
He	2058.20	1.51998	1.52814	
	2500.00	1.51156	1.5195	
	3000.00	1.49962	1.5070	

CHANGE OF THE REFRACTIVE INDICES OF QUARTZ (PER DEGREE, FOR RANGE 20 TO 100°C) (56)

Approximate wave-length, mμ	Change of absolute index		Change of index in air	
	$10^6\Delta n_\epsilon$	$10^6\Delta n_\omega$	$10^6\Delta N_\epsilon$	$10^6\Delta N_\omega$
202	+1.29	+1.84	+2.67	+3.21
206	+0.63	+1.19	+1.98	+2.53
210	+0.08	+0.59	+1.45	+1.93
214	−0.49	−0.07	+0.83	+1.24
219	−1.05	−0.57	+0.27	+0.74
224	−1.79	−1.13	−0.48	+0.17
226	−2.04	−1.36	−0.75	−0.08
228	−2.22	−1.55	−0.93	−0.27
231	−2.41	−1.80	−1.12	−0.52
257	−3.89	−3.09	−2.65	−1.86
274	−4.44	−3.55	−3.23	−2.35
288	−5.06	−3.99	−3.85	−2.79
298	−5.34	−4.29	−4.15	−3.11
313	−5.68	−4.65	−4.50	−3.48
325	−5.87	−4.69	−4.69	−3.52
340	−6.17	−5.08	−5.01	−3.93
361	−6.40	−5.32	−5.25	−4.18
441	−7.05	−5.87	−5.93	−4.75
467	−7.15	−5.96	−6.01	−4.85
480	−7.22	−6.10	−6.10	−4.99
508	−7.29	−6.25	−6.16	−5.14
589	−7.54	−6.50	−6.42	−5.39
643	−7.64	−6.60	−6.53	−5.49

CHANGE OF REFRACTIVE INDEX OF VITREOUS SILICA PER DEGREE, FOR RANGE 20 TO 100°C (52)

Radiating element	Approx. wave-length	Change of absolute index, $10^6\Delta n$	Change of index in air, $10^6\Delta N$
Al	185	23.19	24.61
Al	186	22.71	24.13
Al	193	20.80	22.17
Al	198	19.65	21.00
Zn	206	18.32	19.64
Zn	210	17.50	18.81
Cd	214	17.28	18.57
Zn	215	17.01	18.30
Cd	219	16.66	17.94
Cd	224	15.70	16.97
Cd	226	15.90	17.16
Cd	231	16.99	18.24
Cd	232	15.26	16.51
Cd	257	13.74	14.95
Cd	274	13.01	14.20
Cd	288	12.32	13.49

CHANGE OF REFRACTIVE INDEX OF VITREOUS SILICA.—(*Continued*)

Radiating element	Approx. wave-length	Change of absolute index, $10^6\Delta n$	Change of index in air, $10^6\Delta N$
Cd	298	12.25	13.41
Cd	325.5	11.99	13.14
Cd	346	11.41	12.55
Cd	361	11.27	12.40
Cd	441	10.41	11.51
Cd	480	10.20	11.29
Cd	508	10.21	11.29

VITREOUS SILICA AT VARIOUS TEMPERATURES; ABSOLUTE INDEX OF REFRACTION CALCULATED FROM DATA OF RINNE (71)

Temp., °C	He, blue	He, green	He, yellow	He, red
	λ = 471.315mμ	501.568	587.563	667.815
− 160	1.4635	1.4617	1.4581	1.4559
− 64	1.4641	1.4624	1.4586	1.4563
+ 18	1.4649	1.4629	1.4592	1.4569
130	1.4660	1.4642	1.4604	1.4579
235	1.4675	1.4654	1.4616	1.4591
365	1.4692	1.4672	1.4633	1.4608
475	1.4708	1.4689	1.4649	1.4625
590	1.4722	1.4703	1.4663	1.4639
1000		1.4772	1.4729	1.4706

See further p. 343.

Dispersion

CONSTANTS IN THE FORMULA: $n^2 = m + \frac{m_1\lambda^2}{\lambda^2 - \lambda_1^2} - k\lambda^2$; λ and λ_1 in μ at 18°, *in vacuo* (53, 54)

	m	m_1	λ_1	k
Quartz, n_ϵ	1.43813	0.95014	0.106692	0.01723
Quartz, n_ω (1904)	1.42919	0.93173	0.105805	0.01635
Quartz, n_ω (1906)	1.40090	0.95650	0.10495	0.01093
Vitreous, n	1.36112	0.74655	0.107044	0.01350

EFFECT OF TEMPERATURE, CHANGE PER DEGREE C (54)

	$10^6\Delta m$	$10^6\Delta m_1$	$10^6\Delta\lambda_1$ in μ	Δk
Quartz, n_ϵ	67.838	−80.195	6.3200	0
Quartz, n_ω	69.390	−80.048	6.3200	0
Vitreous silica	69.400	−41.832	6.3200	0

Optical Rotation

QUARTZ AT 20°C (2, 6, 8, 23, 31, 32, 36, 37, 45, 46, 48, 80, 82); *see also* Vol. II, p. 336

Radiating element	Wave-length in air at 15°, mμ	Deg., α/mm
Cd	226.503	201.9
Cd	231.288	190.5
Au	242.796	166.9
Au	250.329	153.9
Cd	274.867	121.10
Sn	303.412	95.02
Cd	340.365	72.45
Fe	348.534	68.585
Ca	396.848	51.115
Hg	404.656	48.945
H	410.174	47.495
H	434.047	41.924

Continued on p. 343

Refractive Index.—(*Continued from p. 342*)

QUARTZ AT VARIOUS TEMPERATURES, AS MEASURED BY RINNE AND KOLB [72] AND RECALCULATED AS ABSOLUTE INDICES

Extraordinary index, n_ϵ

Solar line	Wave length, mμ	−140°	−45°	+23°	115°	212°	305°	410°	550°	580°	650°	765°
G′ (H_γ)	434.047		1.5633	1.5634	1.5629	1.5623	1.5615	1.5598	1.5551	1.5503	1.5521	1.5532
(d)	466.8		1.5609	1.5608	1.5603	1.5597	1.5588	1.5572	1.5526	1.5478	1.5492	1.5506
F	486.133	1.5594	1.5594	1.5593	1.5589	1.5581	1.5573	1.5558	1.5512	1.5464	1.5475	1.5490
(c)	495.75		1.5587	1.5587	1.5582	1.5576	1.5567	1.5552	1.5503	1.5456	1.5468	1.5481
b_2	517.27		1.5574	1.5574	1.5568	1.5562	1.5553	1.5538	1.5488	1.5442	1.5454	1.5469
D_2	588.997	1.5541	1.5539	1.5537	1.5532	1.5526	1.5515	1.5499	1.5451	1.5405	1.5417	1.5431
α	627.8	1.5526	1.5525	1.5522	1.5517	1.5510	1.5500	1.5486	1.5437	1.5389	1.5403	1.5416
C	656.278		1.5516	1.5513	1.5508	1.5502	1.5491	1.5475	1.5427	1.5380	1.5393	1.5406
B	687.2	1.5506	1.5506	1.5504	1.5499	1.5492	1.5481	1.5466	1.5419	1.5369	1.5383	1.5397
a	718.9		1.5499	1.5495	1.5490	1.5483	1.5472	1.5458	1.5408	1.5362	1.5375	1.5388

Ordinary index, n_ω

Solar line	Wave length, mμ	−140°	−45°	+23°	115°	212°	305°	410°	550°	580°	650°	765°
G′ (H_γ)	434.047		1.5539	1.5540	1.5536	1.5531	1.5523	1.5510	1.5469	1.5425	1.5439	1.5454
(d)	466.8		1.5515	1.5514	1.5511	1.5506	1.5498	1.5483	1.5442	1.5400	1.5414	1.5429
F	486.133	1.5504	1.5501	1.5500	1.5497	1.5491	1.5483	1.5469	1.5426	1.5385	1.5399	1.5414
(c)	495.75		1.5494	1.5494	1.5491	1.5485	1.5477	1.5465	1.5421	1.5379	1.5393	1.5406
b_2	517.27		1.5481	1.5481	1.5476	1.5472	1.5463	1.5452	1.5407	1.5363	1.5377	1.5392
D_2	588.997	1.5449	1.5448	1.5446	1.5441	1.5437	1.5428	1.5414	1.5370	1.5329	1.5341	1.5356
α	627.8	1.5434	1.5434	1.5431	1.5427	1.5422	1.5413	1.5401	1.5357	1.5314	1.5328	1.5340
C	656.278		1.5425	1.5423	1.5418	1.5414	1.5405	1.5390	1.5349	1.5304	1.5319	1.5331
B	687.2	1.5417	1.5416	1.5414	1.5410	1.5405	1.5395	1.5382	1.5337	1.5296	1.5309	1.5321
a	718.9		1.5408	1.5405	1.5401	1.5396	1.5386	1.5374	1.5327	1.5288	1.5301	1.5313

Optical Rotation.—(*Continued from p. 342*)

Radiating element	Wave-length in air at 15°, mμ	Deg., α/mm
Hg	435.834	41.548
Cd	467.815	35.601
H (solar line "F")	486.133	32.761
Cd	508.582	29.728
Hg	546.072	25.535
Na (mean)	589.29	21.724
Cd	643.847	18.023
Li	670.786	16.535
He	728.135	13.924
Rb	794.763	11.589
Hg	1014.06	6.976
	1200.00	4.889
Hg	1529.61	2.930
He	2058.20	1.527
	2500.00	0.972

CHANGE OF THE ROTATORY POWER OF QUARTZ WITH TEMPERATURE

Ratio of the measured rotation at temperature t to the measured rotation of the same plate at 0°C [2, 3, 31, 40, 42, 43, 57]

t, °C	α_t/α_0	t, °C	α_t/α_0	t, °C	α_t/α_0
−200	0.979	200	1.031	600	1.164
−100	0.988	300	1.050	700	1.166
0	1.000	400	1.071	800	1.167
+ 50	1.007	500	1.100	900	1.169
100	1.014	573	1.132 1.163	1000	1.171

Reflectivity

Wave-lengths of the maxima of reflection by quartz, as given by various observers [11, 44, 59, 65, 75, 77.1, 88]

Observer	Quartz, ω							
Nichols (1897)	8.42		8.80					
Rubens and Nichols	8.50		9.02				20.75	
Rosenthal (1899)	8.49		9.03					
Coblentz (1906)	8.48			12.5				
Coblentz (1908)	8.3–8.5		9.02					
Reinkober (1910)	8.40*		9.02†	9.20‡	12.52	14.55		
Trowbridge and Wood	8.41		8.90					
Liebisch and Rubens							21.0	26.0
	Quartz, ε							
Reinkober (1910)	8.40*	8.70	9.02†		12.87			
Liebisch and Rubens							19.7	27.5
	Vitreous silica							
Coblentz (1908)	8.3		8.8					
Reinkober (1910)	8.30		8.90		12.6	14.6		
Liebisch and Rubens							21.2	26.8

* Center of mass of two maxima, one at 8.35, and one at 8.50 (weak).
† Center of mass of two maxima, one at 8.90, and one at 9.05.
‡ Weak.

Verdet Constant

SODIUM LIGHT AT ROOM TEMPERATURE

Values of $10^3\omega$. $\omega = \alpha/lH$. α in minutes, l in cm, H in gilbert per cm.

Quartz, 17; vitreous, 15. Temperature coefficient about +0.01% per degree C [4, 45, 83].

DISPERSION OF THE VERDET CONSTANT

Source	Wave-length, mμ	Quartz, Verdet constant, $10^3\omega$ (4)	
		At 20°	At 96°
Cd, 25	219.462	158.66	
Cd, 18	257.304	107.90	
Cd, 9	361.25	46.17	
Cd, 6	467.815	27.50	27.72
Cd, 5	479.991	25.74	
Cd, 4	508.582	22.57	
D	589.29	16.64	16.82
Cd, 1	643.847	13.68	13.79

DISPERSION-RATIOS FOR VERDET CONSTANT OF QUARTZ

Radiating element	Wave-length, mμ	Ratio to D line			
		(4)	(21)	(45)	(37)
Cd_{25}	219.462	9.534			
Cd_{18}	257.304	6.484			
Cd_9	361.25	2.775			
Hg	404.656		2.137		
Hg	435.834		1.852	1.912	
Cd_6	467.815	1.653			
Cd_5	479.991	1.547		1.477	
Hg	491.60		1.456		
Cd_4	508.582	1.356		1.372	
Hg	546.072		1.171	1.175	
	549.5				1.158
Hg	579.066		1.041		
D	589.29	1.000	1.000	1.000	1.000
	600				0.963
Cd_1	643.847	0.822			
H	656.278		0.800		
Li	670.786			0.760	
	700				0.690
	800				0.529
	900				0.415
	1000				0.330
	1100				0.269
	1200				0.224
	1300				0.1915
	1400				0.1663
	1500				0.1444
	1600				0.1266
	1700				0.1125
	1800				0.0987
	1900				0.0869
	2000				0.0761
	2140				0.0627

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ambronn, *Diss.*, Göttingen, 1913. *Verh. Kais. Leopold.-Carol. Akad. Naturf.-Halle*, **101**: 177; 15. (2) Bates, *31A*, **2**: 239; 06. (3) Becquerel, *34*, **147**: 1281; 08. (4) Borel, *149*, **16**: 24, 157; 03. (5) Bowen and Andersen, *12*, **37**: 487; 14. (6) Buisson, *34*, **142**: 881; 06. (7) Bush and Connell, *143*, **194**: 231; 22. (8) Carvallo, *6*, **26**: 113; 92. (9) Carvallo, *34*, **126**: 728; 98.

(10) Clews and Thompson, *4*, **121**: 1442; 22. (11) Coblentz, *152*, **No. 65**; 06. **No. 97**; 08. (12) Curie, *Thesis*, Paris, 1888. *6*, **17**: 385; 89. **18**: 203; 89. (13) Curie, *34*, **116**: 136; 93. (14) Curie, *Traité de radioactivité*, **I**: 105. Paris, Gauthier-Villars, 1910. (15) Curie and Curie, *34*, **93**: 204; 81. (16) Curtis, *2*, **34**: 154; 12. (17) Curtis, *31A*, **11**: 359; 15. (18) Czermak, *75*, **96 II**: 1217; 88. (19) Danker, *190B*, **4**: 241; 86.

(20) Day, Shepherd and Wright, *12*, **22**: 265; 06. (21) Disch, *Diss.*, Freiburg, 1903. *8*, **12**: 1153; 03. (22) Doelter, *75*, **117 I**: 845; 08. **119 I**: 49; 10. (23) Dongier, *6*, **14**: 331; 98. (24) Dufet, *191*, **13**: 271; 90. (25) Endell and Rieke, *481*, **31**: 501; 12. (26) Exner, *88*, **3**: 26; 01. (27) Fellinger, *8*, **7**: 333; 02. (28) Fenner, *12*, **36**: 331; 13. (28.1) Ferry, *3*, **44**: 404; 97. (29) Gifford, *5*, **70**: 329; 02. **84**: 193; 10.

(30) Gifford and Shenstone, *5*, **73**: 201; 04. (31) Gumlich, *89*, **2**: 201; 95. *243*, **16**: 97; 96. (32) Gumlich, *8*, **64**: 333; 98. (33) Hayashi, *Diss.*, Göttingen, 1912. (34) Hlawatsch, *94*, **27**: 605; 97. (35) Horton, *3*, **11**: 505; 06. (36) Hussell, *8*, **43**: 498; 91. (37) Ingersoll, *2*, **9**: 257; 17. (38) Jaeger. *Diss.*, Berlin, 1917. (39) Jaquerod and Mügeli, *149*, **4**: 10; 22.

(40) Joubert, *51*, **8**: 5; 79. (41) Koenigsberger, *8*, **66**: 698; 98. (42) von Lang, *75*, **71 II**: 707; 75. (43) Le Chatelier, *34*, **109**: 264; 89. (44) Liebisch and Rubens, *76*, **1919**: 198; 876. (45) Lowry, *62*, **212A**: 261; 12. (46) Lowry, *B2*, **4**: 537; 23. (47) Macé de Lépinay, *51*, **6**: 190; 87. *6*, **5**: 210; 95. (48) Macé de Lépinay, *51*, **9**: 644; 00. (49) Macé de Lépinay and Buisson, *6*, **2**: 78; 04.

(50) Mallard, *191*, **13**: 161; 90. (51) Martens, *8*, **6**: 603; 01. **8**: 459; 02. (52) Martens, *88*, **6**: 308; 04. (53) Martens, *B76*, **VI**. (54) Martens and Micheli, *88*, **6**: 311; 04. (55) Merwin, *12*, **32**: 429; 11. (56) Micheli, *149*, **13**: 217; 02. *8*, **7**: 772; 02. (57) Molby, *2*, **28**: 57; 09. **31**: 291; 10. (58) Müller, *Publ. Astrophys. Obs. Potsdam*, **4**: 149; 85. (59) Nichols, *2*, **4**: 297; 97. *8*, **60**: 401; 97.

(60) Paschen, *8*, **35**: 1005; 11. (61) Pérard, *51*, **3**: 252; 22. (63) Pockels, *536*, **39**: 1; 94. (64) Ramdohr, *189*, **1920**: 33. (65) Reinkober, *8*, **34**: 343; 11. (67) Richardson, *5*, **92**: 41; 16. (68) Richardson, *5*, **92**: 101; 16. **107**:101; 25. (69) Riecke and Voigt, *8*, **45**: 523; 92.

(70) Riedel, *7*, **46**: 408; 03. (71) Rinne, *190B*, **39**: 388; 14. (72) Rinne and Kolb, *190*, **1910 II**: 138. (73) Röntgen, *8*, **18**: 213; 83. (74) Röntgen and Joffé, *8*, **41**: 449; 13. (75) Rosenthal, *8*, **68**: 783; 99. (76) Rubens, *8*, **54**: 476; 95. (77) Rubens, *76*, **1915**: 4. (77.1) Rubens and Nichols, *8*, **60**: 418; 97. (78) Schaller, *U. S. Geol. Sur., Bull.*, **640**: 125; 16. (79) Schmidt, *8*, **9**: 919; 02.

(80) Schönrock, *243*, **21**: 150; 01. (81) Schulze, *8*, **14**: 384; 04. (82) Soret and Sarasin, *149*, **8**: 5, 97, 201; 82. (83) Stierlin, *242*, **52**: 382; 07. (84) Tegetmeier and Warburg, *8*, **32**: 442; 87. (85) Thornton, *5*, **82**: 422; 09. (86) Thornton, *3*, **19**: 390; 10. (87) Trommsdorff, *Diss.*, Jena, 1901. (88) Trowbridge and Wood, *3*, **20**: 898; 10. (89) Voigt and Kinoshita, *188*, **1907**: 123. *8*, **24**: 492; 07.

(90) Warburg and Tegetmeier, *8*, **35**: 455; 88. (91) Washburn and Navias, *38*, **5**: 565; 22. (92) van der Willigen, *502*, **2**: 153; 69. **3**: 34; 74. (93) Wilson, *105*, **2**: 177; 18. (94) Wistrand, *Thesis*, Upsala, 1916.

MAGNETISM

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ATOMIC AND MOLECULAR DATA IN RELATION TO THEORIES OF MAGNETISM

S. J. Barnett

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A body can be magnetized either by placing it in a magnetic field or by rotating it in a neutral region (p. 347). The magnetization acquired in a magnetic field results from the superposition of two effects, either of which may practically vanish: (1) A *magnetic* effect, consisting in an alignment, more or less parallel to the applied magnetic field, of the axes of certain permanent, or approximately permanent, *magnetic elements* constituting parts of the molecules; and (2) a *diamagnetic* effect, fundamentally identical with the induction of an electric current in a conductor (88). In *diamagnetic* substances χ is negative, small, independent of H and, in many cases, independent of temperature and certain other physical conditions. *Magnetic* substances, for which χ is positive, are either *paramagnetic* or *ferromagnetic*. In *paramagnetic* substances χ is small and independent of H at ordinary temperatures and in weak fields. In *ferromagnetic* substances χ is relatively large and depends upon H, unless H is very small. When its temperature is sufficiently increased, every ferromagnetic substance becomes transformed into a paramagnetic substance. The temperature at which this change occurs is called the *temperature of transformation* or *Curie point* (Θ) for the substance. The data given in this report refer chiefly to paramagnetic and diamagnetic substances, because only a few pertinent quantitative atomic and molecular data are available for ferromagnetic substances.

SYMBOLS AND UNITS

Unless another is indicated, the basic unit in every case is the appropriate cgsm unit. Symbols which are frequently used throughout the Tables are defined in Vol. I, p. 16; those used in only a single section will be defined where used.

A Atomic weight.
a Constant in Langevin's equation (p. 350).
B Number of Bohr magnetons per basal unit; $[\mu] = B[\mu]_B$.
e Electric charge; usually, but not necessarily, it is numerically equal to the "electronic charge," **e**.
H Intensity of magnetic field.
j Angular momentum of the body, or system, under consideration.
M Molecular weight.
m Mass.
$\mathbf{m}_0$ Electronic mass at low velocity.
N_0 Avogadro's number.
R Gas constant per gram-mole.
R_0 $2\mathbf{m}_0/\mathbf{e}$.
r Radius.
T Absolute temperature, °K.
W Number of Weiss magnetons per basal unit; $[\mu] = W[\mu]_W$.
Z Atomic number.
Θ Curie point. Temperature-constant in Weiss's relation.
$[\mu]$ Magnetic moment of the system under consideration.
$[\mu_0]$ Magnetic moment of elementary magnetic unit.
Σ Sign of summation.
σ Specific magnetization = magnetic moment per unit of mass.
σ_∞ Value of σ when axes of all the elementary magnetic moments are parallel.
χ Specific susceptibility = susceptibility divided by density.

Subscripts: $_{a,\ m}$ indicates the quantity is referred to the gram-atom, gram-mole. $_{B,\ W}$ indicates the quantity is expressed in the Bohr magneton, the Weiss magneton, as unit moment.

Magnetons or Magnetic Elements

The term *magneton* has been applied both to the complete magnetic element within the atom or molecule, and to the ultimate magnetic units of which the element may be constituted. Of the various magnetons which have been proposed, four will be considered here; the first three are based upon theory, the fourth entirely upon experiment.

Spinning Electron (1, 32, 63, 97, 115).—The element is the rotating spherical electron. The ratio of the angular momentum (j) to the magnetic moment $[\mu]$ is $(j/[\mu])_s = m_s/e$ if the charge is distributed uniformly over the surface, and $(j/[\mu])_v = 5m_v/7e$ if the charge is distributed uniformly throughout the volume; m_s and m_v are the inertias of the electron in the two cases. If r = radius of the electron, $m_s = 2e^2/3r$. $m_v = 4e^2/5r$.

Bohr Magneton (104).—The electron is revolving in a fixed orbit; $j/[\mu_0] = 2m_0/e(\equiv R_0) = -1.13 \times 10^{-7}$ for a negative electron. On Bohr's theory, the least value of j is $\mathbf{h}/2\pi$, and the corresponding value of $[\mu_0]$ is Bohr's magneton $[\mu_0]_B = \mathbf{eh}/4\pi\mathbf{m}_0 = 9.23 \times 10^{-21}$. The Bohr gram-magneton $[\mu_g]_B$ is defined as $N_0[\mu_0]_B = 5593$ (28, 104); if there is but one such electron orbit per atom, $[\mu_g]_B = [\mu_a]_B$.

Sommerfeld Magneton (104).—On Sommerfeld's spectroscopic theory, the atomic moment of an atom is $[\mu] = gj_1[\mu_0]_B$, where g is Landé's "splitting factor," and the angular momentum of the atom is $j = j_1\mathbf{h}/2\pi$. The quantities j and g are derived from spectroscopic data, and the product gj_1 is known as the spectroscopic magneton number of the atom in the given state.

The magnetic moment of the free neutral atom of a metal may be determined directly from the effect of an intense and non-uniform magnetic field upon a high velocity stream of the vaporized metal in the atomic state (method of Gerlach and Stern) (45, 46, 47, 68, 92, 110, 137). The experimental error in the magneton number ($[\mu]/[\mu_0]_B$), so determined, ranges from 0.02 to 0.3 or 0.4.

Table 1.—Comparison of Magneton Numbers (B) Obtained by Different Methods (45, 46, 47, 68, 92, 110, 137)

$[\mu] = B[\mu_0]_B$; B_{GS}, B_S = value of B obtained by the Gerlach and Stern, and by the spectroscopic method, respectively

Atom	H	Na	K	Cu	Ag	Au	Zn	Cd	Hg
B_{GS}	1	1	1	1	1	1	0	0	0
B_S	1	1	1	1	1	1	0	0	0

Atom	Tl	Sn	Pb	Sb	Bi	Te	Ni	Fe
B_{GS}	$\frac{1}{3}$	0	0	0	(?)	0	$\gtrsim 2$	0
B_S	$\frac{1}{3}$	0	0	0	(?)	(?)	5	*

* Large.

Weiss Magneton (11, 50, 89, 93, 120, 126).—At very low temperatures, χ_a, for both Fe and Ni, approaches asymptotically a definite maximum as the intensity of the field is increased and the temperature is decreased. The limiting values are 1123.6×11 for Fe, and 1123.3×3 for Ni. The value 1123.5 is the magnetic moment of the gram-magneton of Weiss, $[\mu_g]_W$. At very low temperatures, the atoms of Fe and Ni contain, respectively, 11 and 3 Weiss magnetons. The moment of the elementary Weiss magneton is defined as $[\mu_0]_W = 1123.5/N_0 = 1.854 \times 10^{-21}$. Within less than the experimental error, the magnetic moments of the Weiss magnetons are $\frac{1}{5}$ as great as those of the corresponding Bohr magnetons.

Table 2.—Atomic and Molecular Magnetic Moments $[\mu]$ of Ferromagnetic Substances at Low Temperatures: Method of Weiss

$[\mu] = W[\mu_0]_W$

	Fe	Fe*	Fe†	Ni‡	$FeNi_2$
W	11.00	11.00	10.00	3.00	20.0
Lit.	(120, 126)	(90)	(93)	(90, 120, 126)	(90)

	Fe_3Ni_2	Fe_2Ni	Co*	Co†	Fe_2Co
W	27.0	27.0	8.92	8.97	36.1
Lit.	(90)	(90)	(11)	(93)	(93)

* By extrapolation from data for Ni alloys.
† By extrapolation from data for Fe-Co alloys.
‡ *See also* p. 351.

Molecular Gyromagnetic Effects

Magnetization by Rotation (Barnett) (3, 7).—In effect, each magneton is a gyrostat with a magnetic moment parallel to the axis of rotation; when a body containing magnetons is rotated, the directions of their magnetic moments tend to become parallel to the axis of rotation of the body. For a circular cylinder making n rotations per sec about its axis of figure, the resultant magnetic moment (M), so produced parallel to the axis, is $M = C\lambda n = CH$, where C is a constant, $\lambda = 2\pi j/[\mu]$, and H is the intensity of the axial magnetic field that would produce the same moment (M) without rotation; $\lambda(= H/n)$ is called the specific magnetic intensity of rotation for the substance of the rod. On the classical theory, if the magneton is an electron in a Bohr orbit, $\lambda = 2\pi j/[\mu_0] = 4\pi \mathbf{m}_0/\mathbf{e} = 2\pi R_0 = -7.10 \times 10^{-7}$ gauss/rotation per sec. If the magneton is a spherical electron with uniform surface charge (Lorentz) spinning about a diameter, $\lambda = -3.55 \times 10^{-7}$ gauss/rotation per sec. Results of experiments are given in Table 3.

TABLE 3.—MAGNETIZATION BY ROTATION

λ = specific magnetic intensity of rotation = $2\pi j/[\mu]$. For Bohr magneton, $j/[\mu] = R_0$; for spinning electron with surface charge, $j/[\mu] = R_0/2$. $2\pi R_0 = 4\pi \mathbf{m}_0/\mathbf{e} = -7.10 \times 10^{-7}$ gauss/rotation per sec; unit of $\lambda(\equiv H/n) = 10^{-7}$ gauss/rotation per sec.

Material	Notes	$-\lambda$	Material	Notes	$-\lambda$
Steel	*	3.6	Heusler alloy	‡	3.62
Steel	†	3.4	Permalloy	80% Ni‡	3.78
Iron, Steel	6 rods‡	3.79	Ni-Fe	25% Ni‡	3.63
			Co-Fe	35% Co‡	3.83
Nickel	2 rods‡	3.69	Co-Ni	54% Co‡	3.83
Cobalt	‡	3.84			

Weighted mean of observations (‡) of 1923, 3.76 ± 0.07.
Hence $j/[\mu] = (3.76/7.10)R_0 = 0.529R_0 = 1.06\mathbf{m}_0/\mathbf{e}$.
* Observations of 1914, method of electromagnetic induction (3).
† Observations of 1915, method of 1914 (3).
‡ Observations of 1923, magnetometer method (7), error about 2%.

Rotation by Magnetization (Einstein and de Haas (40); *cf.* (9, 30, 39, 96, 105, 108, 109)).—This is the converse of the Barnett effect. A ferromagnetic rod is given an angular momentum about its axis by altering a magnetic field, parallel to the axis, impressed on the rod by means of a solenoid which may be either fixed to the earth or wound rigidly on the rod. The measurements permit the calculation of the ratio $j/[\mu]$ on the basis of the classical theory and the assumption that the momentum acquired by the rigid system which includes the rod is equal and opposite to the momentum given to the magnetons. For the results of the most reliable experiments, *see* Table 4.

TABLE 4.—ROTATION BY MAGNETIZATION

The value of $(j/[\mu])/R_0$ to be expected on the classical theory is unity for a Bohr magneton, and 0.5 for a spinning electron with surface charge.

Material	$(j/[\mu])/R_0$	Method*
Iron	0.50+	Bal (30)
	0.53	ACD (9)
	0.50+	ACN (109)
	0.52	ACN_R (6)
Nickel	0.50+	Bal (30)
	0.57	ACD (9)
	0.50	ACN (109)
Cobalt	0.5	ACN (108)
Permalloy	0.52+	ACN_R (6)
Magnetite	0.5	ACN (108)
Heusler alloy	0.50	ACN (109)

* Bal = ballistic; ACD = alternating current, deflection; ACN = alternating current, null; ACNR = alternating current, null, solenoid wound on rod; ACN_R = both ACN and ACNR. Excepting ACNR, solenoid is fixed to earth. Data from (6) are preliminary.

Magnetism and Structure; *v. also* (108, 109)

Effect of Number of Electrons (*v. also* (19, 61, 62)).—(*a*) Pascal's Relation.—Pascal (82) found that for homologous elements in the 3 families of metalloids, $\chi_a(\equiv A\chi) = -Ce^{\alpha A}$, where C and α are experimental constants; later (85) he found the relation to apply to nearly all the other diamagnetic elements; *see* Fig. 1.

(*b*) Kossel's Relation (16, 64, 104).—For atoms and ions having 18 to 29 electrons external to the nucleus, Kossel observed that the magnetic moment depends primarily upon the number of electrons external to the nucleus; *e.g.*, A, K^+, and Ca^{++} have 18 such electrons each, and their moments are essentially identical (Fig. 2); removing 2 electrons from the neutral Ca atom ($Z = 20$) changes its moment to that of A ($Z = 18$). This illustrates Kossel's "displacement law." Meyer found the same relation for atoms and ions having 57 to 71 extranuclear electrons (Fig. 3).

Effect of Distribution of Electrons and Electron Orbits.—(*a*) Langevin's Theory.—On Langevin's (65) electron theory of magnetism, an ion, atom, or molecule with a completely symmetrical arrangement of electron orbits should be diamagnetic, as exemplified by the rare gases and Cu^+, Ag^+, Au^+; while an unsymmetrical arrangement should produce paramagnetism, as exemplified by Na, K, Ag, Cu, etc.

(*b*) Kossel's and Sidgwick's Theory.—On the theory of Kossel (64) and Sidgwick (102) the electropositive atoms of a saturated compound have lost all the electrons they will part with readily, and the electronegative atoms have taken up all they will take up, and in practically all cases the resulting orbital arrangement is symmetrical, and the compounds are diamagnetic. In a few cases, as in cupric compounds, the arrangement is not symmetrical, and the compound may be paramagnetic. Similarly, unsaturated compounds of diamagnetic elementary substances may be either diamagnetic like oxides of bivalent Pb and Sn, or paramagnetic like NO; *v. also* (10).

(*c*) Lewis's Theory.—On the magnetochemical theory of G. N. Lewis (69), those electrons in a molecule which are paired with one another produce a diamagnetic effect, while an unpaired electron gives a magnetic moment to the molecule, thus producing paramagnetism. In the case of solids and liquids the exact molecular state is in general unknown; but in the case of gases and dilute solutions it can be predicted that every substance with an odd number of electrons in the molecule will be paramagnetic, as exemplified by the following (111): The two odd molecules NO and NO_2 are paramagnetic, while the nitrogen oxides with even molecules are diamagnetic; ClO_2, which is odd, is paramagnetic even in dilute solution in CCl_4; the odd compound α-naphthyldiphenylmethyl in benzene solution is paramagnetic (the first case of paramagnetism in an organic compound); for additional data, *see* (111, 133).

(*d*) Welo and Baudisch's Theory.—On the theory of Welo and Baudisch (127, 128); *cf.* (10), the diamagnetism of certain salts of magnetic elements is due to the fact that the atoms of the magnetic element have, by sharing with, and transfer from, neighboring atoms, gained a sufficient number of electrons to attain the symmetrical electron configuration of a rare gas. Thus $K_4Fe(CN)_6$ is diamagnetic because each K atom contributes one electron to the Fe atom by transfer, and each CN group contributes one by sharing. Thus the Fe atom, originally possessing 26 non-nuclear electrons, gains 10 more, and assumes the structure of Kr with 36 electrons.

Effect of Crystal Structure.—Though numerous experiments, including the recent ones of Ingersoll and de Vinney on magnetic and non-magnetic Ni films (55); *cf.* (80), indicate clearly that ferromagnetism occurs only in crystalline masses, the type of crystal appears to have little significance (52, 129, 130). Thus α-, β- and δ-iron are all body-centered cubic, while γ-iron is face-centered cubic. At ordinary temperatures, Ni is face-centered cubic; Co

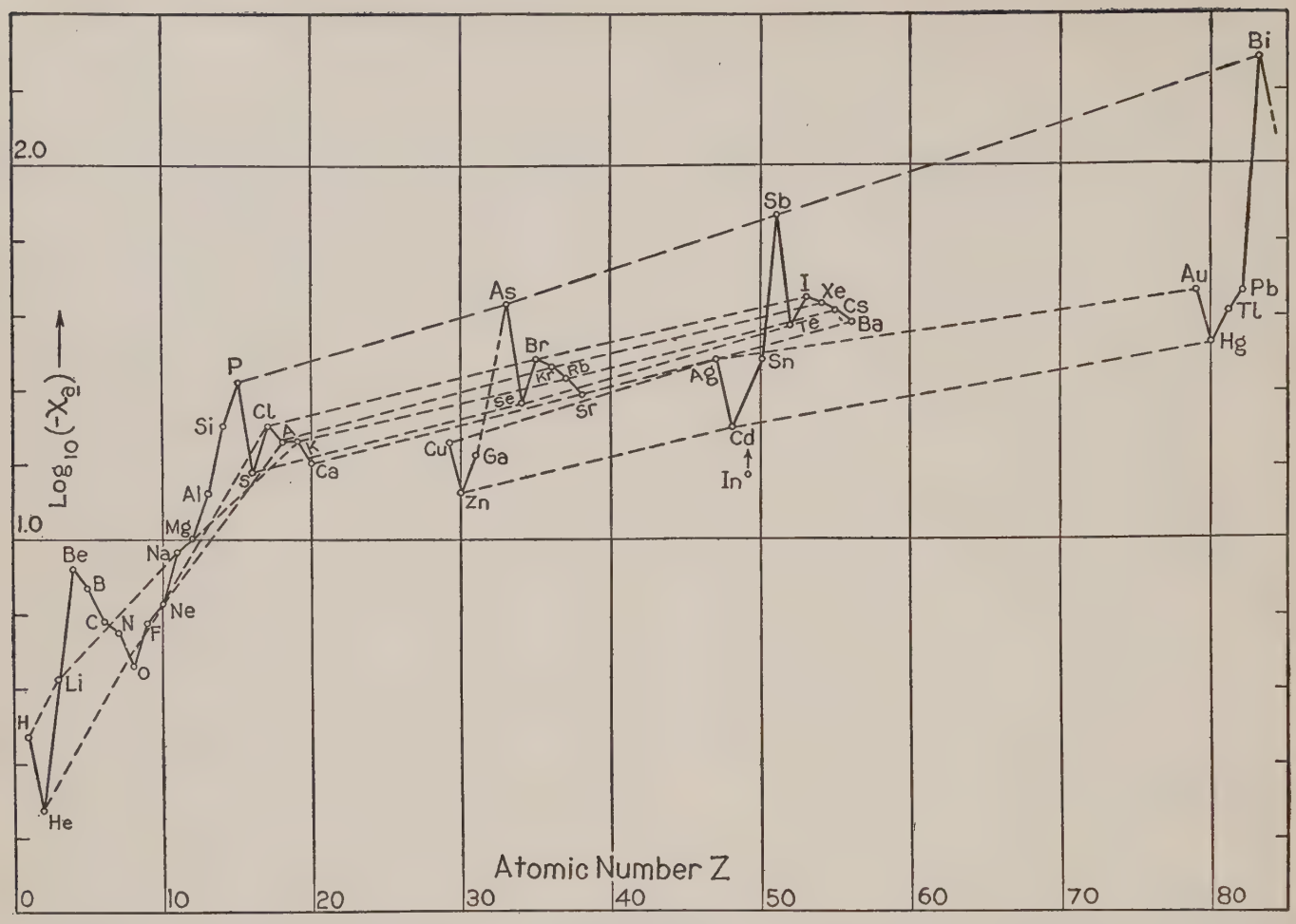

FIG. 1.—Relation between atomic susceptibility (χ_a) of diamagnetic elements and atomic number (Z) (Pascal's relation with A replaced by Z). Data for rare gases ([49], [134]); *cf.* [10], others from Pascal; calculations and interpolations ([15], [19], [32]). Dashed (– – –) lines connect homologous elements and, for $Z > 14$, are nearly straight, as demanded by Pascal's relation (p. 347).

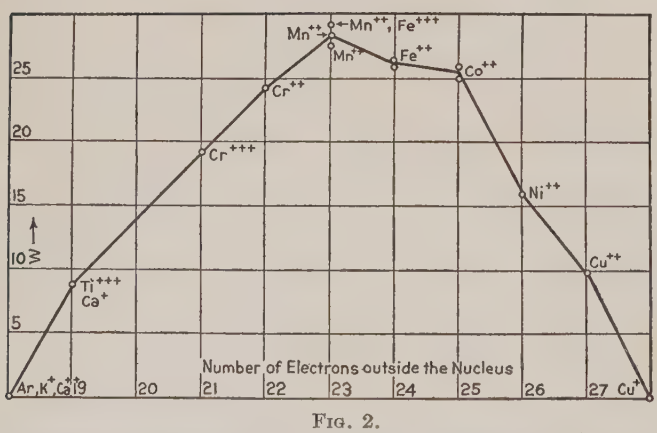

FIG. 2.

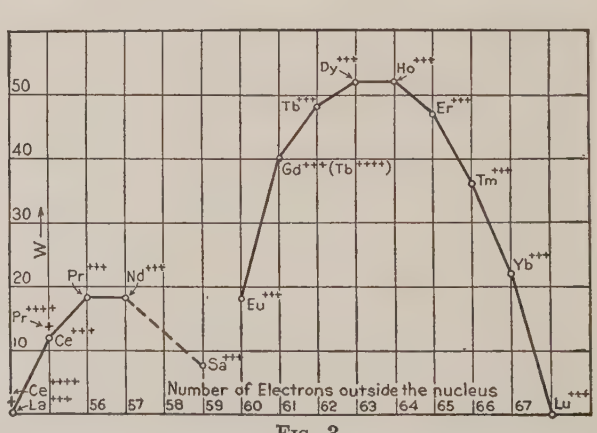

FIG. 3.

FIGS. 2, 3.—Relation between magnetic moment ($[\mu]$) of atom or ion and the number (N) of electrons external to the nucleus (Kossel's relation). $[\mu] = W[\mu_0]_W$, *i.e.*, W = number of Weiss magnetons per atom or ion. In Fig. 2, data from ([104]); in Fig. 3, ° from ([18]), + from ([74]) computations assume the Langevin-Weiss theory (p. 350).

is hexagonal or face-centered cubic; pyrrhotite (Fe_7S_8), hexagonal; magnetite (Fe_3O_4), cubic; and hematite (Fe_2O_3), rhombohedric. Thermomagnetic changes in Heusler alloy are not accompanied by any change in the X-ray diffraction pattern (139), and the pattern of Fe-Ni alloys does not change when the composition passes through that of the extremely permeable permalloy (2). Paramagnetic and diamagnetic solids have a great variety of crystal forms, though in certain groups homologous elements have the same crystal structure (10). Magnetization may produce no change in the crystal structure (138); *e.g.*, Laue photographs of crystals of magnetite and of hematite are unchanged by a field of 1000 gauss (34), and those of Heusler alloy are unchanged by 3500 gauss (139), and the X-ray spectra obtained by reflection from a crystal of magnetite are not affected in any way by subjecting the crystal to a strong magnetic field (33); *cf.* (138).

Additivity Relations

Simple Additivity.—The law of additivity may be written $m\chi = \Sigma m_i\chi_i$, where m_i is the mass of a constituent i of a compound or mixture (M) of mass $m = \Sigma m_i$, and χ and χ_i are the specific susceptibilities of M and the constituent i. The summation (Σ) is extended to all constituents. For many compounds and mixtures, this law appears to be valid; for many others, the departures from it are great.

Table 5.—Additivity Relation as Applied to Solid Paramagnetic Hydrates (43)

Some data satisfy the relation $m\chi = \Sigma m_i\chi_i$, and some do not. χ_o = observed specific susceptibility; χ_c = specific susceptibility calculated from data in last column by subtracting the (negative) susceptibility of the H_2O lost. Error $\lesssim 1\%$; unit of $\chi = 10^{-6}$ cgsm unit.

H_2O	None		$1H_2O$		nH_2O	
Salt	χ_o	χ_c	χ_o	χ_c	n	χ_o
$CuSO_4$	8.6	9.6	8.6	8.6	5	5.9
$NiSO_4$	25.5	27.8	24.1	23.8	6	15.6
$CoSO_4$	60.8	60.0	53.6	53.2	7	3.5
$Sm_2(SO_4)_3$	3.43	3.39			8	2.6
$Gd_2(SO_4)_3$	92.6	92.7			8	74.7

As applied to solutions, the law of additivity requires that the molecular susceptibility of the solute be independent of the concentration; this is known as *Wiedemann's law.* In many cases of apparent failure of Wiedemann's law, it is probable that more than one type of each of certain constituents is present and that the relative amounts of these types change with the concentration. Hydrolysis furnishes an illustration of such changes. When a salt is hydrolyzed in a solution, the value of χ for the ion, as deduced from that for the solution on the assumption that the simple additivity relation holds, commonly differs from that deduced from observations taken under other conditions. In such cases, progressive reduction of hydrolysis by addition of acid enables one to extrapolate to the condition of no hydrolysis; this extrapolated value for the ion frequently agrees with that found under other conditions of no hydrolysis (15, 23, 41, 94).

As applied to molecules, the additivity relation requires that the molecular susceptibility $\chi_m (\equiv M\chi)$ shall be computable from the atomic (ionic) susceptibilities of the constituent atoms (ions). Pascal so applied it, and found that consistent results could be obtained in many cases, especially of saturated organic compounds. Weiss similarly applied the relation in determining the ionic susceptibilities of metals, from the observed susceptibilities of salts and solutions; *v.* (118).

Table 6.—Atomic and Atomic-Group Susceptibilities (82, 83, 84)

The values given below are in general use in determining ionic susceptibilities of metals, and assume that $m\chi$ for H_2O is 13.0×10^{-6}. $m\chi$ = atomic or atomic-group susceptibility; in the former case, m = atomic weight; in the latter, m = formula weight of the group; unit of $m\chi = 10^{-6}$.

Atom	Br	C	Cl	F	H	Hg	I	K	Na	O
$-m\chi$	30.6	6.0	20.1	6.3	2.93	33.4	44.6	18.5	9.2	4.6

Atom or atom group	P	S	Se	Te	H_2O	SO_4	NO_3	NH_3	CN
$-m\chi$	26.3	15.0	23.1	37.5	13.0	33.6	14.2	14.4	10.8

Pascal's Relation (82, 83).—In those cases in which the application to molecules of the simple additivity relation led to inconsistent results, Pascal employed the more general equation $M\chi = \Sigma n_i A_i \chi_i + \lambda$, or its equivalent $\chi_m = \Sigma n_i \chi a_i + \lambda$, in which n_i is the number of atoms of species i and atomic weight A_i that are contained in a molecule of molecular weight M, and λ measures the deviation from the law of additivity; λ depends upon the nature of the molecule. Frequently, λ has the same value for all those organic compounds which are of similar type. Thus, if unit of χ is 10^{-7},

$$(m\chi)_{(C_6H_5Cl)} - (m\chi)_{(C_6H_5Br)} = 103$$

and

$$(m\chi)_{(CH_2ClCO_2C_2H_5)} - (m\chi)_{(CH_2BrCO_2C_2H_5)} = 107$$

while

$$(m\chi)_{Cl} - (m\chi)_{Br} = 105;$$

also

$$(m\chi)_{(C_6H_5Br)} - (m\chi)_{(C_6H_5I)} = 138$$

and

$$(m\chi)_{(CH_2BrCO_2C_2H_5)} - (m\chi)_{(CH_2ICO_2C_2H_5)} = 148$$

while

$$(m\chi)_{Br} - (m\chi)_{I} = 140;$$

the differences for the compounds are uncertain by 8 or 10 units. For values of λ, *see* Table 7.

Table 7.—Pascal's λ for Certain Bonds in Organic Compounds

$M\chi = \Sigma n_i A_i \chi_i + \lambda$. For the saturated C_nH_{2n+2} compounds, $\lambda = 0$; unit of $\chi = 10^{-6}$ cgsm unit

Bond	λ	Bond	λ
Benzene bond	−1.5	Polyethylene bond	+10.6
Naphthalene bond	−6.1	C = O	+ 8.2
Hexamethylene bond	+3.0	C ≡ N	+ 0.8
Ethylene bond	+5.5	C ≡ N	0

Table 8.—Effective Atomic Susceptibility $(\chi_a)_O$ of O in Organic Compounds

Assumes $\lambda = 0$; unit of $(\chi_a)_O = 10^{-6}$ cgsm unit

Type of bond	$(\chi_a)_O$
Singly bound to any two atoms, —O—	−4.6
Doubly bound to a single C not carrying another O	+1.7
Doubly bound to a single C carrying a second O	−3.4

Doubly bound to any single polyvalent atom: $(a\chi_O)$ is of the same sign as for the corresponding case in which the C is the polyvalent atom.

Theories of Diamagnetism

The Weber-Langevin Theory (65, 116).—On this theory the magnetic moment of a diamagnetic atom in a neutral region is zero because the electron orbits are such and so arranged that the vector sum of their individual moments is zero. The orbits are assumed to be rigid, independent of T, and in general unaffected by chemical and physical changes; but *the velocities of the electrons in the orbits are changed by the application of a magnetic field.* On this last the existence of diamagnetism depends. On this theory, for an isotropic substance, or for atoms oriented at random, $\chi_a =$

$-(e^2N_0/12\pi m_0)\Sigma n_i a_i$; a_i = area of an orbit of type i; n_i = number of such orbits per atom. Variations in χ_a may result from a *paramagnetic* relative displacement of the orbits, from distortion, due to a molecular electric or magnetic field, when a change of state occurs (69, 81, 82, 83) (Oxley (81) attributes to such fields intensities of the order of 10^7 gauss, *cf. infra*), and in the case of conductors, possibly but not certainly (67), from the presence of free electrons (99, 135).

TABLE 9.—EFFECT OF LIQUEFACTION OF DIAMAGNETIC SOLIDS: ILLUSTRATIVE (81)

If $\delta\chi/\chi$ is positive, the liquid is more diamagnetic than the solid; unit of $\delta\chi/\chi = 1\%$

Substance		$\delta\chi/\chi$	Lit.
H_2O	Water	3+	(56)
Hg	Mercury	14	(81)
C_6H_6	Benzene	0	(81)
C_6H_7N	Aniline	5	(81)
C_7H_5ClO	Benzoyl chloride	−5	(81)
C_7H_8	Toluene	5	(81)
C_8H_{10}	*o*-Xylene	5	(81)

Pauli's Theory.—On this theory (4, 86) which is applicable only to monatomic gases, diamagnetism is due to a *rotation of the complete atom* (Larmor rotation) produced by the magnetic field. For random orientation, χ_a is just twice as great as on the *Weber-Langevin* theory, *i.e.*, $\chi_a = -(e^2N_0/6\pi m_0)\Sigma n_i a_i$.

Atomic Radii

From measurements of the susceptibility of a diamagnetic substance it is possible, on the basis of either of these theories, to compute the mean of the areas of the several electronic orbits in the atom and the radius (r) of this mean area, assumed to be circular. The value obtained for r depends upon the theory applied. By the use of Bohr's theory of the atom, it is possible, in certain cases, to derive from r the radius (r_m) of the outermost orbit (19, 62). The effective atomic radius can also be obtained from viscosity and other data. For numerical values of the several r's, *see* Table 10.

TABLE 10.—ATOMIC RADII

The radii are derived as follows:

$r_w[r_p]$ From mean area of the electronic orbits as given by the Weber-Langevin [the Pauli] theory (15, 19); $r_w = r_p\sqrt{2}$.

r_m Mean radius of outer shell of electrons, as computed by Cabrera (19) from observations of Wills and Hector (49, 134); where 2 values are given (ions of A structure) they are based on slightly different assumptions.

r_v From measurements of viscosity; computed by Jeans (60).

r_c From crystal data by method of Fajans and Herzfeld (42); computed by Grimm (48).

r_l From Landé's atomic model, cubical symmetry; computed by Schwendenwein (100).

r_b Radius of combination, Bragg (12).

Unit of $r = 1\mu\mu = 10^{-6}\mu = 10^{-10}$ cm

(1)	r_w	r_p	r_m	r_v	r_c	r_l	r_b
A	85	60	85	181	87	109	105
Ca^{++}			69, 74		67		170
Cl	92	65		168			
Cl^-			98, 92		95		105
F^-			55		75		
H	146	103		177			
He	81	57	57	111			
Hg	55	39		105			
K	84	59		159			
K^+			76, 80		79		207
Kr			103	205	97	112	
Mg^{++}			39		39		
N	76	54		146			
N^{---}			77				
Na^+			43		52		
Ne	68	48	54	111	63	74	
O	65	46		146			
O^{--}			65		89		
P^{---}			137, 111				
S^{--}			113, 101		109		102
Xe			144	242	110	126	

Theories of Paramagnetism

χ is Independent of the Temperature.—No detailed theory has been developed; *see*, however (124).

χ Varies with the Temperature.—(*a*) Langevin's Theory.—Langevin has developed a fundamental theory for gases, and on this many other theories have been based (*see infra* and p. 352). His theory leads to the relation $\sigma_a/\sigma_{a\infty}$ $(= \sigma/\sigma_\infty) = \coth a - 1/a$, where $a \equiv \sigma_{a\infty}H/RT$. If a is small, the relation becomes σ_a/H $(\equiv \chi_a) = (\sigma_{a\infty})^2/3RT = C_a/T$; or, divided by A, $\chi = C/T$, which is Curie's law (36). Curie's law is valid for O_2 both at high temperatures and (83), if density corresponds to a pressure of 100 atm. at 290°K, within the ranges 170 to 290°K and 10 to 18 kilogauss, C being $(302.8 \pm 1.5) \times 10^{-4}$; it is also valid for certain solids and solutions of salts, *see infra* and Tables 11, 12, 14.

Proceeding on quite different assumptions, Weiss has shown that in certain cases Langevin's relation may be valid for solid bodies (119), and it has been established experimentally (Onnes, Oosterhuis, Woltjer) (75, 136) for solid gadolinium sulfate, $Gd_2(SO_4)_3 \cdot 8H_2O$, over the ranges 1.3 to 300°K and 3.3 to 22 kilogauss; a was varied from a small value to 7.0; Curie's law applies if $a < 0.7$.

(*b*) Weiss's Generalization of Langevin's Theory.—Weiss and Onnes independently observed that many series of data for which Curie's law fails satisfy the more general relation $\chi(T - \Theta) = C$ (Weiss's law), and Weiss has shown that Langevin's theory leads to this expression when the orientations of the elementary moments are modified by intense molecular fields; $C_a = (\sigma_{a\infty})^2/3R$, as in Langevin's theory when a is small. The intensities of the molecular fields necessary to account for the observed values of Θ exceed 10^6 gauss if assumed to be magnetic; some of the values, as estimated by Weiss (122), are, in this unit: Fe, 6.5; Ni, 6.4; Co, 8.9; magnetite, 14.3.

If the elementary magnetic moments were each accompanied by an electric moment having the same axis, the resultant molecular electrical field would produce the same effect as the molecular magnetic field at first assumed by Weiss (121). The required elementary electric moment is $\epsilon = 1.5\sqrt{RM\Theta/\pi dN_0}$ electrostatic units, where d = density of the substance, and other symbols have same significance as elsewhere. Thus if the unit of ϵ is 10^{-18} cgse unit, the values of ϵ for Fe, Co, and Ni are, respectively, 1.09, 1.25, and 0.85, if the atom is the basal element; if the basal element for Fe is 3 atoms and for magnetite is $0.5Fe_3O_4$, the corresponding values of ϵ are 1.90 for Fe and 1.74 for Fe_3O_4. All these values are very close to those (0.34 to 1.18) obtained by Debye (37, 73) for the moments of dipoles in insulators. The value given for Ni is much the most reliable.

An explanation of the existence of Θ in mixtures of oxygen and nitrogen (*cf.* Table 14) has been given in terms of polymerization (70, 89).

For solutions, experiments of Foëx (44) and of Cabrera and Duperier (21) have shown that in general Θ is not zero; and the results of the latter indicate that Θ is independent of the concentration and of the nature of the anion.

For substances which are ferromagnetic at ordinary temperatures, Weiss's theory interprets Θ as the temperature at which the

substance becomes paramagnetic (Curie point, critical temperature). For pure Fe-Ni alloys ranging from Fe_2Ni (34.4% Ni) to 100% Ni, Weiss's law is followed exactly from temperatures near the Curie point to *ca.* 1200°C, and Θ is found (91) to be a little higher than the Curie point. From many series of observations at Zürich (120), the atomic magnetic moment $[\mu]$ for pure Ni above the Curie point, calculated on the basis of the Langevin-Weiss theory, has been found to be $[\mu] = (8.02 \pm 0.02)\ [\mu_0]_W$; *cf.* p. 346.

For other ferromagnetic substances at temperatures above the Curie point, Weiss's law is not certainly followed even over moderate ranges of T.

For most paramagnetic substances, it holds over a considerable range of T, but, in general, fails at very low temperatures. This failure constitutes the *cryomagnetic anomaly* of Onnes. For ions both of the iron group and of the rare earth groups, Cabrera (20) has shown that Θ in general decreases with increase of ionic magnetic moment, the relation for ions of a given class being linear.

TABLE 11.—WEISS'S LAW AS APPLIED TO PARAMAGNETIC SOLIDS: VALUES OF Θ AND RANGES OF VALIDITY; ILLUSTRATIVE

Weiss's law, $\chi(T - \Theta) = C$, usually fails at very low temperatures. Range of T = range over which the law holds good; T' = temperature below the range; *a*, *m*, *s* indicate whether χ and C refer to the atomic (metal atom), molecular, or specific magnetization. Error in Θ ranges *ca.* from <1 to 2°K; unit of $\chi = 1$ cgsm; of T, T', and $\Theta = 1$°K.

Substance	(2)	Range of T	Θ	C	$\chi(T' - \Theta)$	T'	Lit.
$Gd(C_2H_5SO_4)_3.9H_2O$	*a**	14.6–291.5	0	7.05			(58)
$CoSO_4$	*m*	77.3–289.5	− 45	3.22	4.27	14.8	(57)
$NiSO_4.7H_2O$	*m**	169.6–292.2	+ 59	1.077	3.76	14.6	(57)
Pt†	*s*	325 –685	−1124	0.001663	0.001651	289	(44)
Pd†	*s*	479 –722	− 226	0.003043	0.002997	290	(44)
$Fe_2(NH_4)_2(SO_4)_4.24H_2O$	*m*	14.7–290	0	8.50			(78)
Dy_2O_3	*m*	13.9–288.5	− 16	27.6			(76)

* Values have been corrected for diamagnetism of the anion and of the water of crystallization.

† Values have been corrected for diamagnetism of the metal atom.

TABLE 12.—WEISS'S LAW AS APPLIED TO PARAMAGNETIC SOLIDS: VARIATION OF Θ WITH MOLECULAR CONSTITUTION

$\chi(T - \Theta) = C$; mean error in $\Theta = 2°$, maximum error = 7°K; unit of $\Theta = 1$°K

Cation	Ni^{++}		Co^{++}		Fe^{++}		Fe^{+++}	
Anion*	Θ	Lit.	Θ	Lit.	Θ	Lit.	Θ	Lit.
SO_4	−79	(57)	−45	(57)	−12	(14)†	−66	(14)†
			−30‡	(112)	−31	(57)		
			−19§	(57)				
			−48	(101)				
$SO_4.7H_2O$	+59	(57)	−14	(57)	− 1	(57)		
$(NH_4)_2(SO_4)_4$							−12	(14)†
$(NH_4)_2(SO_4)_2.6H_2O$	− 4	(57)	−22	(57)	+ 3	(57)	0	(78)
Cl_2	+78‡	(112)	+47	(112)	+30	(14)†	− 3	(14)†
	+38§	(112)	+34	(14)†				

* For Fe^{+++} the salts are $Fe_2(SO_4)_3$, $Fe_2(NH_4)_2(SO_4)_4$, $Fe_2(NH_4)_2(SO_4)_4.24H_2O$, and $FeCl_3$.

† Computed from the data of (51, 56).

‡ At lower temperatures.

§ At higher temperatures.

TABLE 13.—WEISS'S LAW AS APPLIED TO SOLUTIONS AND A PURE LIQUID: VALUES OF Θ AND RANGES OF VALIDITY

$\chi(T - \Theta) = C$; errors in C range from 0.1% to 0.2%. Discrepancies in Θ for a given ion are probably accidental. Solvent is H_2O unless another is indicated. Conc. = concentration, grams of solute per 100 g of solution, except where otherwise indicated; unit of $\Theta = 1$°K; T = absolute temperature, °K.

TABLE 13.—(*Continued*)

Solute	Conc.	Range of T	Θ	Lit.
$MnCl_2$	3.0	293–373	−28	(21)
	15.0	293–376	−25	(21)
	37.9	293–371	−24	(21)
$Mn(NO_3)_2$	6.4	293–373	−23	(21)
	36.9	293–372	−27	(21)
$FeCl_3$*	0.148	290–400	−11	(44)
	0.148	290–400	+ 2	(44)
	0.161	290–400	+ 1	(44)
	0.183	290–400	− 4	(44)
$Fe(NH_4)_2(SO_4)_2.6H_2O$†	0.0315	290–373	0	(44)
	0.0405	291–384	− 1	(44)
$CoCl_2$	7.9	283–413	−11.6	(29)
	14.8	283–413	−12.1	(29)
$CoSO_4$	4.1	283–413	−11.2	(29)
	9.8	283–413	−12	(29)
$Co(NO_3)_2$	9.4	283–413	−12.4	(29)
	0.076*	290–400	− 2	(44)
	0.139*	290–400	− 3	(44)
	0.139*	290–400	−17	(44)
$NiCl_2$	4.6	279–363	0	(123)
	4.6‡	292–329	0	(123)
	Satd.§	290–400	0	(44)
$Ni(NO_3)_2$	12.4	293–370	− 4.2	(21)
	44.4	293–375	− 1.4	(21)
$V_2O_2Cl_4.5H_2O$‖	100	194–326	−29	(88)
	100	194–326	−45	(88)

* Conc. = grams of metal per 100 g solution; limits of T only approximate.

† Conc. = grams of Fe per 100 g solution; solvent is mixture of H_2O and H_2SO_4.

‡ Solvent is H_2O + 6.8% NH_3.

§ Solution is saturated, concentration $\lesssim$ 20% Ni; limits of T only approximate.

‖ A viscous liquid.

TABLE 14.—WEISS'S LAW AS APPLIED TO MIXTURE OF O_2 AND N_2 (89)

V_O = volume of O_2 contained in volume V at the same temperature and pressure. $\chi(T - \Theta) = C$. Mean error in Θ *ca.* 0.2°; unit of $\Theta = 1$°K; of $\chi = 10^{-4}$ cgsm unit.

V_O/V	1 (8)	$\frac{3}{5}$	$\frac{1}{3}$	$\frac{2}{11}$	$\frac{1}{5}$	$\frac{1}{8}$	Mean C
C	315.8	315.3	314.7	315	315.3	315	315.2
Θ		−29.5	−16.5	−9.5	−4.5	−2.2	

TABLE 15.—MAGNETIC MOMENTS $[\mu]$ OF MOLECULES AND IONS OF PARAMAGNETIC SUBSTANCES

I. Molecules. Only O_2 and NO. Computation based on Langevin's theory (p. 350) and assumption of a single fixed moment.

II. Ions. Except where otherwise stated: For solutions, solvent is H_2O, Wiedemann's law is valid, and Curie's law is assumed without having been established. For solid salts, Weiss's law is valid within the "range" indicated. Computation is based on the Langevin-Weiss theory (p. 350).

In column (1) is named the ion or molecule considered and in (2), the molecule from which it is derived. The pure substance is a solid salt unless the contrary is indicated by g = gas, or l = liquid; $[\mu]$ refers to the gram-ion (-molecule) or to the individual ion (molecule) according as $[\mu]_W = [\mu_g]_W$ or $[\mu_0]_W$. $[\mu] = W[\mu]_W$. t = centigrade temperature, °C.

TABLE 15.—(*Continued*)

State of substance		Solution		Pure		
(1)	(2)	W	Lit.	Range of t	W	Lit.
O_2	O_2.....			g	14.1s	(8, 120)
NO	NO.....			g	9.1s	(8, 120)
Cu^{++}	Various.....	9.5 9.8	(24)			
	$CuCl_2$.....			+ 20 −+500	10.0	(51, 56, 118)
	$CuSO_4$.....			−120 −+700	9.96	(51, 56, 118)
Mn^{++}	$MnCl_2$.....	28.05*	(21)	−180 −+630	27.04	(51, 56, 118)
				+ 15 −+575	28.45	(112)
	$MnSO_4$.....			+ 9 −+270	29.04	(112)
				+280 −+550	29.04	(112)
	$MnSO_4.4H_2O$..			− 68.6−+ 28.5	29.04	(44)
	$Mn(NO_3)_2$.....	28.07*	(21)			
Fe^{++}	$FeCl_2$.....			−182 −+200	25.9	(51, 56, 118)
	$FeCl_2.4H_2O$....			−180 −+ 20	26.0	(51, 56, 118)
	$FeSO_4$.....			−177 −+660	26.08	(51, 56, 118)
	$FeSO_4.7H_2O$...	26.51	(125)	−173 −+ 23	26.0	(51, 56, 118)
	$Fe(NH_4)_2$- $(SO_4)_2.6H_2O$..	26.49	(125)	− 73 −+ 16	25.97	(44)
Fe^{+++}	$Fe_2(SO_4)_3$.....			−180 −+660	29.00	(51, 56, 118)
				+ 16 −+575	28.95	(112)
	$Fe_2(NH_4)_2$- $(SO_4)_4$.....			−180 −+400	29.0	(51, 56, 118)
Co^{++}	$CoCl_2$.....	25.06*	(29)	+ 15.5−+325	24.96	(112)
	$CoSO_4$.....	25.03*	(29)	+ 15 −+550	25.00	(112)
				−196 −+ 16	25.2	(57)
	$CoSO_4$†.....	26.03*	(29)	+ 8 −+422	26.0	(101)
	$CoSO_4.7H_2O$...			−209 −+ 17	25.04	(57)
	$Co(NH_4)_2$- $(SO_4)_2.6H_2O$..			−196 −+ 17.5	24.75	(57)
	$Co(NO_3)_2$.....	25.02*	(29, 44)			
		25.54*	(44)			
Ni^{++}	$NiCl_2$.....	16.02*	(13, 25, 123)	−120 −+360	16.08	(51, 56, 118)
				+ 15 −+125	16.03	(112)
				+150 −+500	16.92	(112)
	$NiSO_4$.....	16.06	(25, 123)	−180 −+120	17	(51, 56, 118)
				−196 −+ 16	16.9	(57)
	$Ni(NO_3)_2$.....	16.04	(25, 123)			
		15.96*	(21)			
	$NiCl_2 + NiSO_4$ $+ Ni(NO_3)_2$‡.	15.58*	(123)			
Cr^{++}	$CrCl_2$.....	23.72 23.89	(27)			
	$CrSO_4.7H_2O$...	23.98	(27)			
Cr^{+++}	$Cr_2O_3.7H_2O$...			−164 −+ 19	19.07	(51, 56, 118)
	$CrCl_3$.....			−167 −+ 18	18.87	(51, 56, 118)
				+250 −+550	18.87	(51, 56, 118)
	$CrCl_3.4H_2O$....	18.72§	(41)			
	$CrCl_3.6H_2O$....	18.77§	(41)			
	$Cr_2(SO_4)_3$.....	18.89	(22)			
	$Cr(NO_3)_3$‖.....	18.99	(22)			
V^{++++}	$V_2O_2Cl_4.5H_2O$¶	**		l	7.94	(88)
	$VOSO_4.3\frac{1}{2}H_2O$.	**		− 79 −+100	8.95	(88)

Rare earths; salt of type $R_2(SO_4)_3.8H_2O$, except where noted (15, 18, 74, 131, 132)††

Ion^{+++}	La	Ce‡‡	Pr	Nd	Nd§§	Sa
W.....	0	11.89	17.89	18.00	18.05	7.64(?)
$\pm\delta W$.....		1.2	0.3	0.3	1	
δP.....		−1.1	−0.6	0.0	+0.3	

* Weiss's law found to be valid, value of Θ was found and used in computation.

† Anhydrous salt prepared by calcining $CoSO_4.7H_2O$.

‡ Solvent is $H_2O + xNH_3$.

§ Hydrolysis is very weak and value of W closely approaches 19.00 as hydrolysis is reduced by addition of HCl.

‖ Hydrolysis is very weak.

¶ A viscous liquid.

** Erculisse finds the same moments (W = 8 and 9) when V^{++++} occurs in aqueous solutions (88).

†† As Curie's law has been found to be valid for $Gd_2(SO_4)_3.8H_2O$ (*see* p. 350), Θ has been assumed to be 0 for the sulfates. δW = % uncertainty in W; δP = % departure of W from nearest integer.

‡‡ $Ce_2(SO_4)_3.5H_2O$.

§§ Oxide.

TABLE 15.—(*Continued*)

Ion^{+++}	Eu	Gd	Tb	Dy	Dy§§	Ho
W.....	17.92	40.07	47.92	52.25	52.00	52.00
$\pm\delta W$.....	0.1	0.2	0.4	0.3	0.3	0.2
δP.....	−0.4	+0.2	−0.2	+0.5	0.0	0.0

Ion^{+++}	Er	Er§§	Tm	Yb	Lu
W.....	46.98	47.09	35.85	21.74	0
$\pm\delta W$.....	0.3	1	0.1	0.2	
δP.....	−0.0	+0.2	−0.4	−1.2	

§§ Oxide.

(*c*) *Energy Quantization Theories.*—The most thoroughgoing of several investigations modifying Langevin's theory (p. 350) by introducing energy quantization, are those of Reiche (95) and Rotzahn (98). The theory so developed for gases leads to relations which frequently accord with the data for solids more satisfactorily than do those of Weiss and others, especially at very low temperatures. It accounts for the Θ in Weiss's law and permits the computation of the value of χ at 0°K, but it is consistent with only that type of cryomagnetic anomaly in which $d(\chi^{-1})/dT$ decreases with T. For the equations and their derivation, *see* (67, 69).

TABLE 16.—REICHE-ROTZAHN THEORY AS APPLIED TO PARAMAGNETIC SOLIDS: ILLUSTRATIVE

χ_0 = value of χ at 0°K; $\chi_{obs.}$, $\chi_{calc.}$ = observed (51, 76, 79), calculated from Reiche-Rotzahn theory by means of parameters derived from the observations. $\Delta = (\chi_{obs.} - \chi_{calc.})/\chi_{calc}$; Δ_m = mean value of Δ; $[\Delta]_m$ = mean of the absolute values of Δ (irrespective of sign); $[\mu]_R$ and $[\mu]_L$ = $[\mu]$ of the gram-molecule, as derived from the Reiche-Rotzahn and the Langevin theory, respectively. Range of T = range over which the theory accords with observations. $(\chi T)_l[(\chi T)_h]$ = value of χT at the lowest [highest] temperature of the range. Values of $[\mu]_R$ are from (5); unit of $\chi = 10^{-6}$; of Δ_m and $[\Delta]_m$ = 1%; of $[\mu]_R$ and $[\mu]_L = 10^{-20}$; T = absolute temperature, °K.

Solid	Range of T	$(\chi T)_l$	$(\chi T)_h$	Δ_m
$MnSO_4$.....	19.4–293.9	9 158	25 804	+0.50
$MnSO_4.4H_2O$.....	14.4–288.7	17 755	19 141	−0.47
$FeSO_4.7H_2O$.....	14.7–293.2	11 113	12 394	+0.17
$Fe_2(SO_4)_3$.....	64.0–289.8	11 334	15 446	+0.09

Solid	Range of T	$[\Delta]_m$	χ_0	$[\mu]_R$	$[\mu]_L$
$MnSO_4$.....	19.4–293.9	0.92	658	5.35	5.12
$MnSO_4.4H_2O$.....	14.4–288.7	0.88	7 294	5.45	5.13
$FeSO_4.7H_2O$.....	14.7–293.2	0.41	3 365	4.90	4.82
$Fe_2(SO_4)_3$.....	64.0–289.8	0.27	286	6.84	7.11

(*d*) *Spatial Quantization Theories* (87, 103, 104).—The Zeeman spectroscopic effects suggest a spatial quantization of the axes of the elementary magnets. Pauli (87) introduced this assumption into Langevin's theory for gases (p. 350). As modified by Sommerfeld it gives $\chi_a T(\equiv C_a) = \left\{\frac{[\mu]^2 N_0^2}{3R}\right\}\left\{\frac{j_1+1}{j_1}\right\}$, where $[\mu]$ and j_1 refer to the atom, and $[\mu] = gj_1[\mu_0]_B$ (*see* p. 346). Hence $\sqrt{3RC_a}/N_0[\mu_0]_B(=2.83\sqrt{C_a}) = g\sqrt{j_1(j_1+1)}$. In certain cases, g and j_1 can be determined with considerable certainty from chemical and spectroscopic data. The most conspicuous success in verifying the formula by such means has been obtained by Hund with the triply ionized rare earths, Z = 57 to Z = 71 (*see* Table 17). Similar attempts with ions of elements from Z = 18 to Z = 29 have been only partially successful, probably because at ordinary temperatures the atoms are not all in the state of excitation assumed to characterize the gas. For attempts at correlation between atomic constitution and magnetic moments, Z = 18 to 29, *see* (20, 38, 53, 66, 104). For discussion of other theories of spatial quantization, *see* (73).

TABLE 17.—PAULI-SOMMERFELD THEORY AS APPLIED BY HUND TO THE RARE EARTHS (53, 54)

This theory requires that $2.83\sqrt{C_a}$ ($\equiv 2.83\sqrt{\chi_a T}$) shall equal $g\sqrt{j_1(j_1+1)}$, where g and j_1 are numbers determined from spectroscopic and chemical data; $gj_1 = [\mu]/[\mu_0]_B \equiv B$. In the following it is supposed that the 4_{33} and lower shells are completed, and that the 5_1, 5_2, and 5_3 shells contain 2, 2, and 4 electrons, respectively. In columns (3), (4), and (5) are given the number of electrons in the shells 4_4, 4_{43}, and 4_{44}; in (6), the fundamental spectral term; in (9) $B_c \equiv W/5$ for solid salt (Table 15); in (10), $g\sqrt{j_1(j_1+1)}$, computed value of $2.83\sqrt{\chi_a T}$; in (11) and (12), values of $2.83\sqrt{\chi_a T}$ as determined by Cabrera (20) and Meyer (74). Columns (4), (5), and (9) are not given by Hund.

(1) Z	(2) Ion*	(3) 4_4	(4) 4_{43}	(5) 4_{44}	(6) Sp.	(7) j_1	(8) g	(9) B_c	(10) comp.	(11) obs.	(12) obs.
57	La.....	0	0	0	^1S	0	$\frac{8}{9}$	0	0.00†	0	0
58	Ce.....	1	1	0	^2F	$\frac{5}{2}$	$\frac{6}{7}$	2.38	2.54	2.39	2.77‡
59	Pr.....	2	2	0	^3H	4	$\frac{4}{5}$	3.58	3.58	3.60	3.47
60	Nd.....	3	3	0	^4J	$\frac{9}{2}$	$\frac{8}{11}$	3.60	3.62	3.62	3.51
61		4	4	0	^5J	4	$\frac{3}{5}$		2.68		
62	Sa.....	5	5	0	^6H	$\frac{5}{2}$	$\frac{2}{7}$	1.53	0.84	1.54(?)	1.32
63	Eu§.....	6	6	0	^7F	0	$\frac{8}{9}$	3.58	0.00†	3.61	3.12
64	Gd.....	7	6	1	^8S	$\frac{7}{2}$	2	8.01	7.9	8.2	8.1
65	Tb.....	8	6	2	^7F	6	$\frac{2}{3}$	9.58	9.7	9.6	9.0
66	Dy.....	9	6	3	^6H	$\frac{15}{2}$	$\frac{4}{3}$	10.45	10.6	10.5	10.6
67	Ho.....	10	6	4	^5J	8	$\frac{5}{4}$	10.4	10.6	10.5	10.4
68	Er.....	11	6	5	^4J	$\frac{15}{2}$	$\frac{8}{5}$	9.4	9.6	9.5	9.4
69	Tm.....	12	6	6	^3H	6	$\frac{7}{6}$	7.2	7.5	7.2	7.5
70	Yb.....	13	6	7	^2F	$\frac{7}{2}$	$\frac{8}{7}$	4.4	4.5	4.4	4.6
71	Lu.....	14	6	8	^1S	0	$\frac{2}{3}$	0	0.00†	0	0

* Elements are triply ionized.

† Assumes $g = 0$.

‡ Perhaps Pr^{++++}.

§ Discrepancy may be due to Gd as an impurity, or a considerable fraction of the Eu ions may not be in fundamental state.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abraham, *8*, **10**: 105; 03. (2) Arnold and Elmen, *143*, **195**: 621; 23. (3) Barnett, *2*, **6**: 239; 15. **10**: 7; 17. (4) Barnett, *2*, **25**: 835; 25. (5) Barnett, *8*, **77**: 98; 25. (6) Barnett, *0*. (7) Barnett and Barnett, *65*, **60**: 125; 25. (8) Bauer and Piccard, *51*, **1**: 97; 20. (9) Beck, *8*, **60**: 109; 19.

(10) Bieler, *143*, **203**: 211; 27. (11) Bloch, *6*, **26**: 5; 12. (12) Bragg, *3*, **40**: 169; 20. (13) Brant, *2*, **17**: 678; 21. (14) Cabrera, *132*, **16**: 436; 18. (15) Cabrera, *42*, **16**: 442; 18. (16) Cabrera, *51*, **3**: 443; 22. (17) Cabrera, *132*, **21**: 505; 23. (18) Cabrera, *132*, **23**: 151; 25. (19) Cabrera, *51*, **6**: 241; 25.

(20) Cabrera, *51*, **6**: 273; 25. (21) Cabrera and Duperier, *51*, **6**: 121; 25. (22) Cabrera and Marquina, *132*, **15**: 199; 17. (23) Cabrera and Moles, *132*, **10**: 316, 394; 12. (24) Cabrera and Moles, *132*, **12**: 373; 14. (25) Cabrera, Moles and Guzman, *132*, **12**: 121; 14. (26) Cabrera, Moles and Marquina, *132*, **13**: 256; 15. (27) Cabrera and Piña de Rubies, *132*, **17**: 149; 19. (28) Chalmers, *58*, **92**: 687; 14. (29) Chatillon, *34*, **181**: 778; 25.

(30) Chattock and Bates, *62*, **233**: 257; 23. (31) Cherbuliez, *Thesis*, Zürich, 1917. (32) Compton, *143*, **192**: 145; 21. (33) Compton and Rognley, *2*, **16**: 464; 20. (34) Compton and Trousdale, *2*, **5**: 315; 15. (35) Crow, *69*, **19 III**: 63; 25. (36) Curie, *6*, **5**: 289; 95. (37) Debye, *63*, **13**: 97, 295; 12. (38) Dorfman, *96*, **23**: 286; 24. (39) Einstein, *88*, **17**: 203; 15. **18**: 173; 16.

(40) Einstein and de Haas, *88*, **17**: 152; 15. (41) Elias, *132*, **16**: 467; 18. (42) Fajans and Hertzfeld, *96*, **2**: 309; 20. (43) Feytis, *34*, **153**: 666; 11. (44) Foëx, *6*, **16**: 174; 21. (45) Gerlach, *8*, **76**: 163; 25. (46) Gerlach and Cilliers, *96*, **26**: 106; 24. (47) Gerlach and Stern, *8*, **74**: 673; 24. (48) Grimm, *7*, **98**: 353; 21. (49) Hector, *2*, **24**: 418; 24.

(50) Hegg, *149*, **29**: 529; 10. **30**: 15; 10. (51) Honda and Ishiwara, *159*, **4**: 215; 15. (52) Hull, *2*, **14**: 540; 19. (53) Hund, *96*, **34**: 296; 25. *B1*, p. 180. (54) Hund, *96*, **33**: 855; 25. *B1*, p. 79. (55) Ingersoll and De Vinney, *2*, **26**: 86; 25. (56) Ishiwara, *159*, **3**: 303; 14. (57) Jackson, *62*, **224**: 1; 23. (58) Jackson and Onnes, *34*, **177**: 154; 23. (59) Jacobson, *Thesis*, Zürich, 1916.

(60) Jeans, *Dynamical theory of gases*, 2 ed., p. 341. Cambridge Univ. Press, 1916. (61) Joos, *96*, **19**: 347; 23. (62) Joos, *96*, **32**: 835; 25. (63) Kennard, *2*, **19**: 420; 22. (64) Kossel, *8*, **49**: 229; 16. (65) Langevin, *6*, **5**: 70; 05. (66) Laporte and Sommerfeld, *96*, **40**: 333; 26. (67) Leeuwen, *Thesis*, Leiden, 1919. *51*, **2**: 361; 21. (68) Leu, *96*, **41**: 551; 27. (69) Lewis, *286*, **1**: 231; 24.

(70) Lewis, *1*, **46**: 2027; 24. (71) McKeehan, *143*, **197**: 583, 757; 24. (72) Marx, *B88*, p. 627. (73) Marx, *B88*, p. 668. (74) Meyer, *63*, **26**: 51; 25. (75) Onnes, *64P*, **17**: 283; 14. *168*, **No. 140d.** (76) Onnes and Oosterhuis, *64P*, **15**: 322, 965; 12. *168*, **Nos. 129b, 132e.** (77) Onnes and Oosterhuis, *64P*, **15**: 1404; 13. *168*, **No. 134d.** (78) Onnes and Oosterhuis, *64P*, **16**: 917; 14. *168*, **No. 139e.** (79) Onnes and Perrier, *64P*, **14**: 115; 11. *168*, **No. 122a.**

(80) Oseen, *96*, **32**: 940; 25. (81) Oxley, *62*, **214**: 109; 14. (82) Pascal, *6*, **19**: 5; 10. (83) Pascal, *6*, **25**: 289; 12. (84) Pascal, *34*, **158**: 37, 38; 14. (85) Pascal, *34*, **158**: 1895; 14. (86) Pauli, *96*, **2**: 201; 20. (87) Pauli, *63*, **21**: 615; 20. (88) Perrakis, *34*, **184**: 1430; 27. (89) Perrier and Onnes, *64P*, **16**: 901; 14. *168*, **No. 139e**

(90) Peschard, *34*, **180**: 1836; 25. (91) Peschard, *34*, **181**: 99; 25. (92) Phipps and Taylor, *2*, **29**: 309; 27. (93) Preuss, *Thesis*, Zürich, 1912. (94) Quartaroli, *36*, **46**: 371; 16. (95) Reiche, *8*, **54**: 401; 17. (96) Richardson, *2*, **26**: 248; 08. (97) Richardson, *Institut international de physique Solvay*, **1921**: 220; 1923. (98) Rotzahn, *8*, **57**: 81; 18. (99) Schrödinger, *75*, **121 IIa**: 1305; 12.

(100) Schwendenwein, *96*, **4**: 73; 21. (101) Serres, *34*, **181**: 714; 25. (102) Sidgwick, *4*, **123**: 725; 23. (103) Sommerfeld, *96*, **19**: 221; 23. (104) Sommerfeld, *Atombau und Spektrallinien*. 4th ed., *Chap.* VIII. Braunschweig, Vieweg u. Sohn, 1924. (105) Stewart, *2*, **11**: 100; 18. (106) Stoner, *Magnetism and atomic structure*. New York, Dutton, 1926. (107) Stoner, *3*, **3**: 336; 27. (108) Sucksmith, *5*, **108**: 638; 25. (109) Sucksmith and Bates, *5*, **104**: 499; 23.

(110) Taylor, *2*, **28**: 576; 26. (111) Taylor and Lewis, *197*, **11**: 456; 25. (112) Théodoridès, *51*, **3**: 1; 22. (113) Tolman and Stewart, *2*, **9**: 164; 17. (114) Trümpler, *Thesis*, Zürich, 1917. (115) Uhlenbeck and Goudsmit, *58*, **117**: 264; 26. (116) Weber, *Werke*, III: 555. Berlin, J. Springer, 1893. (117) Weiss, *51*, **6**: 661; 07. (118) Weiss, *51*, **1**: 965; 11. (119) Weiss, *34*, **156**: 1674; 13.

(120) Weiss, *51*, **5**: 129; 24. (121) Weiss, *34*, **178**: 739; 24. (122) Weiss and Beck, *51*, **7**: 249; 08. (123) Weiss and Bruins, *64P*, **18**: 246; 15. (124) Weiss and Collet, *34*, **178**: 2146; 24. (125) Weiss and Frankamp, *64P*, **18**: 254; 15. (126) Weiss and Onnes, *64P*, **12**: 649; 10. *168*, **No. 114.** (127) Welo, *58*, **116**: 359; 25. (128) Welo and Baudisch, *58*, **116**: 606; 25. (129) Westgren and Lindh, *7*, **98**: 181; 21.

(130) Westgren and Phragmén, *7*, **102**: 1; 22. (131) Williams, *2*, **12**: 158; 18. (132) Williams, *2*, **14**: 348; 19. (133) Williams, *Bull. Amer. Phys. Soc.*, **1**: No. 5, p. 15; 25. (134) Wills and Hector, *2*, **23**: 209; 24. (135) Wilson, *5*, **97**: 321; 20. (136) Woltjer and Onnes, *64P*, **26**: 626; 23. (137) Wrede, *96*, **41**: 569; 27. (138) Wyckoff, *Structure of crystals*, p. 403. New York, The Chemical Catalog Co., 1927. (139) Young, *3*, **46**: 291; 23.

PARAMAGNETIC AND DIAMAGNETIC DATA

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The volume susceptibility (κ), the specific susceptibility (χ), the magnetic field intensity (H), the magnetic induction (B), and the density (d) of the material are related as indicated by the equations: $B = (1 + 4\pi\kappa)H$, $\chi = \kappa/d$. In the following tables, the older measurements based upon κ for water have, so far as possible, been reduced to the basis of $\kappa = -0.720 \times 10^{-6}$ for water at 20°C, which is the value now accepted for such work. The older measurements assumed $\kappa = -0.75 \times 10^{-6}$ or -0.79×10^{-6}. When not otherwise specified, room temperature is to be understood.

TABLE 1.—VOLUME SUSCEPTIBILITY (κ) OF GASES

Temperature = 20°C and pressure = 1A_n except as noted; M = mean value; unit of $\kappa = 10^{-9}$ cgsm

	κ	Lit.		κ	Lit.
A	−0.75	(47)	O	+142	M
H	−0.165	M		+140	(20)
	−0.166	(100)		+139	(100)
	−0.164	(125)		+144	(3)
He	−0.078	(47)		+145	(126)
N	−0.40	M	Air*	+ 29.0	M
	−0.31	(100)		+ 29.4	(20)
	−0.49	(47)		+ 28.7	(100)
Ne	−0.28	(47)		+ 29.4	(86, 122)
				+ 28.8	(10)

* For χ, *see* Table 6.

TABLE 2.—SPECIFIC SUSCEPTIBILITY (χ): ELEMENTARY SUBSTANCES

g = gas at 1 atmosphere, l = liquid, s = solid, t = centigrade temperature, M = mean value; temperatures connected by } indicate the range over which χ has been found to have the value stated; unit of $\chi = 10^{-6}$ cgsm.

A-Table

A*			Ag.—(*Continued*)		
t	χ	Lit.	t	χ	Lit.
20	−0.45g	(47)	970 } 1000	−0.28l	(51)
Ag			1125	−0.29l	
18	**−0.20**	M	**Al**		
− 170	−0.16	(79)	18	**0.63**	M
− 140	−0.17		− 170 } 18	0.60	(79)
− 80	−0.18		18	0.65	(51)
− 40	−0.19		230	0.64	
18	−0.20		500 } 657	0.57	
23	−0.20	(51)	658 } 1000	0.57l	(51)
270	−0.23				
840	−0.24				
945	−0.26				

* *See* Table 1.

TABLE 2.—(*Continued*)

As			C.—(*Continued*)		
t	χ	Lit.	t	χ	Lit.
18	**−0.31**	M	− 170	−6.0†	(79)
− 170 } 164	−0.31	(51, 79)	20	−3.5†	
Au			300	−2.7†	
18	**−0.15**	M	600	−2.0†	
− 170 } 1060	−0.15	(51, 79)	900	−1.4†	
1070 } 1230	−0.17l	(51)	1000	−1.3†	
B			20 } 100	−2.0‡	(51)
18	**−0.69**	M	500	−1.8‡	
− 170 } 18	−0.66	(79)	850	−1.6‡	
18	−0.71	(51)	1150	−1.5‡	
100	−0.73		**Ca**		
230	−0.76		− 170 } 18	1.10	(79)
330 } 1100	−0.77		**Cb**		
Ba			18	**1.5**	M
− 170 } 18	0.9	(79)	− 170 } 18	1.65	(79)
Be			18 } 450	1.3	(51)
− 170	−0.75	(79)	**Cd**		
20	−1.0		18	**−0.18**	M
300	−1.2		− 170 } 300	−0.18	(51, 79)
Bi			400	−0.16	(51)
18	**−1.35**	M	500 } 700	−0.15	
− 259	−1.55	(78)	**Ce**		
18	−1.27		− 170	38	(79)
− 160	−1.63	(79)	− 150	35	
− 100	−1.52		− 100	26	
− 60	−1.44		18	15	
20	−1.40		100	12	
18	−1.38	(51)	200	11	
150	−1.19		**Cl**		
260	−1.02		− 60	−0.57l	(81)
280 } 600	−0.08l	(51)	**Cr**		
Br			18	**3.6**	M
18	**−0.39l**	M	− 170 } 18	3.5	(79)
− 170 } − 8	−0.40s	(79)	18	3.7	(51)
− 7 } 18	−0.40l	(79)	500	3.8	
16	−0.39l	(81)	850	4.0	
18	−0.38l	(51)	1100	4.2	
C			**Cs**		
− 170 } 20	−0.49*	(79)	− 170 } 18	−0.10	(79)
20	−0.49*	(51)	**Cu**		
200	−0.50*		18	**−0.086**	M
400	−0.51*		− 170 } 20	−0.085	(79)
900	−0.54*		18 } 100	−0.086	(51)
1200	−0.56*		500	−0.075	
			850 } 1050	−0.070	

* Diamond. † Ceylon graphite. ‡ Gas carbon.

TABLE 2.—(*Continued*)

Er

t	χ	Lit.
18	22	(53)

Ga

t	χ	Lit.
− 170	−0.26	(79)
18	−0.24	
30	−0.23	
30–100	−0.04l	(79)

Ge

t	χ	Lit.
− 170	−0.30	(79)
18	−0.12	
200–890	−0.10	
900	−0.30l	(79)
1000	−0.39l	

H*

t	χ	Lit.
20	**−1.97**g	M
20	−1.98g	(100)
20	−1.96g	(125)
	−2.7l	(78)

He*

t	χ	Lit.
20	−0.47g	(47)

Hg

t	χ	Lit.
18	**−0.19**l	M
− 130–− 40	−0.155s	(80)
− 80	−0.15s	(79)
− 38–18	−0.18l	(79)
− 20–60	−0.185l	(80)
− 20–310	−0.193l	(51)

I

t	χ	Lit.
18	**−0.36**	M
− 160	−0.30	(79)
− 100	−0.32	
− 60	−0.33	
0	−0.35	
20	−0.36	
18–113	−0.35	(20)
25	−0.35	(51)
50	−0.37	
95	−0.38	
113	−0.39	
113	−0.39l	(51)
140	−0.35l	
160	−0.33l	
113–164	−0.35l	(20)

In

t	χ	Lit.
20	−0.11	(51)

Ir

t	χ	Lit.
18	**0.14**	M
− 170–18	0.13	(79)
18	0.15	(51)
200	0.17	
450	0.20	
850	0.26	
1150	0.31	

K

t	χ	Lit.
18	**0.52**	M
− 170–62	0.52	(51, 79)
63–190	0.52l	(51)

La

t	χ	Lit.
− 170–18	1.04	(79)

Li

t	χ	Lit.
− 170–16	0.50	(79)

Mg

t	χ	Lit.
18–650	0.55	(51)
650–700	0.55l	(51)

Mn

t	χ	Lit.
18	**9.9**	M
18	9.7	(55)
18–100	10.0	(53)

Mo

t	χ	Lit.
18–1250	0.04	(51)

N*

t	χ	Lit.
20	**−0.342**g	M
20	−0.265g	(100)
20	−0.419g	(47)

Na

t	χ	Lit.
18	**0.51**	M
− 170–97	0.51	(51, 79)

Nd

t	χ	Lit.
18	36	(79)

Ne*

t	χ	Lit.
20	−0.33g	(47)

O*†

t	χ	Lit.
20	**106.2**g	M
− 259	54s_1	(78)
− 252	56s_1	
− 240	60s_1	
− 240	118s_2	(78)
− 230	115s_2	
− 219	113s_2	
− 219	310l	(78)
− 213	295l	
− 203	273l	
− 196	260l	
20	104.7g	(20)
20	104.1g	(100)
20	107.7g	(3)
20	108.2g	(126)

Os

t	χ	Lit.
18	**0.05**	M
− 170–1100	0.05	(51, 79)

P

t	χ	Lit.
20	**−0.90***	M
− 170–44	−0.90*	(51, 79)
20	−0.67†	(20)
45–120	−0.90l	(51)

Pb

t	χ	Lit.
18	**−0.12**	M
− 170	−0.14	(79)
− 80	−0.13	
18	−0.12	
18–330	−0.12	(51)
330–600	−0.08l	(51)

Pd

t	χ	Lit.
18	**5.4**	M
− 258	10.9	(77)
− 253	9.9	
− 196	8.1	
− 103	6.9	
− 61	6.0	
− 23	5.8	
18	5.3	
− 170	6.7	(79)
− 100	6.2	
− 60	5.8	
0	5.4	
18	5.2	
18	5.8	(51)
200	4.6	
470	3.4	
750	2.6	
940	2.2	
1230	1.7	

Pr

t	χ	Lit.
− 170	90	(79)
− 100	53	
20	25	
200	14	
400	11	
600	8	
900–970	7l	(79)

Pt

t	χ	Lit.
18	**1.10**	M
− 170	1.31	(79)
− 140	1.24	
− 100	1.20	
− 60	1.17	
− 20	1.13	
18	1.10	
18	1.10	(51)
250	0.66	
450	0.56	
700	0.45	
960	0.37	
1220	0.30	

Rb

t	χ	Lit.
18	**0.09**	M
− 170–38	0.08	(79)
18	0.09	(53)

Rh

t	χ	Lit.
18	**1.11**	M
− 180	0.90	(79)
− 100	1.02	
− 40	1.05	
18	1.08	
18	1.14	(51)
280	1.31	
500	1.46	
730	1.52	
915	1.74	
1140	1.86	

Ru

t	χ	Lit.
18	**0.50**	M
− 170	0.55	(79)
− 100	0.50	
− 40	0.46	
18	0.43	
18	0.56	(51)
650	0.64	
750	0.65	
1000	0.70	
1100	0.75	

S

t	χ	Lit.
18	**−0.49‡**	M
− 170–112	−0.49‡	(51, 79)
113–220	−0.49l	(51, 79)

Sb

t	χ	Lit.
18	**−0.87**	M
− 175–18	−0.82	(79)
18–80	−0.92	(51)
150	−0.89	
300	−0.77	
550	−0.55	
640–800	−0.49l	(51)

Se

t	χ	Lit.
18	**−0.32**	M
− 170–219	−0.32	(51, 79)
219–250	−0.32l	(51)

Si

t	χ	Lit.
18	**−0.13**	M
− 170–1000	−0.13	(51, 79)

Sn

t	χ	Lit.
18	**0.025**	M
18	0.02	(79)
18–230	0.027	(51)
18	−0.35§	(51)
240–400	−0.036l	(51)

* *See* Table 1. † Two modifications (s_1, s_2) of solid O.

* White. † Red. ‡ Rhombic. § Gray.

TABLE 2.—(*Continued*)

Sr			Ta			Te			Th			Ti		
t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.
−160 to 18	−0.2	(79)	18	**0.87**	M	18	**−0.31**	M	18	**0.13**	M	−170	1.6	(79)
			−170	0.83	(79)	−160	−0.46	(79)	−170	0.05	(79)	−140	1.4	
			−80	0.82		−100	−0.40		−100	0.06		−110	1.3	
			18	0.81		−60	−0.36		−40	0.07		−80 to 20	1.25	
			18	0.93	(51)	−20	−0.33		20	0.08				
			130	0.91		0	−0.32		18	0.17	(51)			
			420	0.88		18	−0.30		150	0.23				
			540	0.86		18	−0.32	(51)	250 to 390	0.29				
			820	0.77		130	−0.32							
						350	−0.31							
						436	−0.31							
						470	−0.071l	(51)						
						525	−0.046l							

Tl*			U			V			W			Yt			Zn			Zr		
t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.	t	χ	Lit.
18	**−0.24**	M	18	2.6	(79)	18	**1.4**	M	18	**0.28**	M	−160	16.8	(79)	18	**−0.157**	M	18	**−0.45**	M
18	−0.23α	(79)				−170 to 20	1.2	(79)	−170 to 18	0.22	(79)	−100	11.3		−170 to 150	−0.157	(51, 79)	−170 to 400	−0.45	(51, 79)
28	−0.25α	(51)				18 to 350	1.5	(51)	18 to 1100	0.33	(51)	20	5.3		450 to 600	−0.09l	(51)			
115	−0.24α					750	1.6					200 to 400	2.8							
220	−0.23α					1100	1.8													
234 to 291	−0.19β	(51)																		
300 to 440	−0.17l	(51)																		

* Two modifications (α, β) of Tl.

TABLE 3.—SPECIFIC SUSCEPTIBILITY (χ): PURE INORGANIC COMPOUNDS

t = centigrade temperature; g = gas at 1 atmosphere; l = liquid; s = solid; Aq = determined from measurements of aqueous solutions, assuming the simple additivity relation is applicable to χ. St. Meyer's original data (73) assume for Hg, at 18°C, $\chi = -0.151 \times 10^{-6}$; for this table they have been multiplied by 19/15; unit of $\chi = 10^{-6}$ cgsm.

𝔅-Table, Standard Arrangement; *v.* Vol. III, p. viii

Formula	t	χ	Lit.
H_2O	20	**−0.720l**	M (21, 55, 89, 98, 122, 125)
	−120 to 0	−0.699s	(55)
HCl	22	−0.661	(32)
SO_2		−0.285l	(82)
SO_3	16	−0.289	(82)

TABLE 3.—(*Continued*)

Formula	t	χ	Lit.
H_2SO_4	22	−0.441	(32)
H_2SeO_3	18	−0.36	(73)
TeO_2	18	−0.14	(73)
H_2TeO_3	15	−0.24	(73)
H_2TeO_4	18	−0.43	(73)
NO	22	48.66g	(100)
NO_2	135	3.26g	(100)
N_2O	12	−0.429l	(100)
	16	−0.429g	(100)
N_2O_3	18	−0.206l	(100)
N_2O_4	−16	−0.276s	(100)
N_2O_5	16	−0.332s	(100)
NH_3	16	−1.1g	(81)
HNO_3	22	−0.467	(32)
NH_2HSO_3		−0.441	(84)
P_2O_5	18	−0.46	(73)
$(NH_4)H_2PO_4$		−0.50	(71)
As_2O_3	18	−0.27	(73)
As_2S_3	18	−0.03	(73)
Sb_2O_3	14	−0.19	(73)
SbF_3		−0.255	(84)
$SbCl_3$		−0.364	(82)
$SbCl_5$		−0.371	(82)
$SbBr_3$		−0.275	(82)
Bi_2O_3		−0.170	(32)
$HBiO_2$	15	−0.22	(73)
$BiCl_3$		−0.322	(44)
$BiBr_3$		−0.328	(44)
BiI_3	20	−0.49	(73)
Bi_2S_3		−0.385	(44)
Bi_2Se_3		−0.342	(44)
$Bi(NO_3)_3.5H_2O$		−0.365	(44)
CO_2	20	−0.423g	(100)
CS_2		−0.54	(71)
$Bi_2(CO_3)_3$		−0.16	(73)
SiO_2 (*cf.* p. 341)		−0.493	(83)
$SiO(OH)_2$		−0.427	(83)
$Si(OH)_4$		−0.443	(83)
$Si_2O(OH)_6$		−0.429	(83)
$SiCl_4$		−0.537	(82)
$SiCl_3.SiCl_3$		−0.513	(82)
$SiHCl_3$		−0.515	(82)
$SiBr_4$		−0.360	(82)
$Si(OC_2H_5)_4$		−0.663	(83)
$Si_2O(OC_2H_5)_6$		−0.635	(83)
$SiC_2H_5Cl_3$		−0.593	(82)
TiO_2		0.066	(115)
Ti_3O_5		8.1	(115)
TiS_2		0.56	(115)
Ti_2S_3		0.91	(115)
ZrO_2	15	−0.112	(73)
SnO	17	−0.11	(73)
SnO_2	15	−0.050	(73)
Sn_2O_3	16	−0.33	(73)
$SnO(OH)_2$		−0.278	(84)
$Sn(OH)_4$		−0.321	(84)
$SnCl_2$	18	−0.37	(73)
$SnCl_4$		−0.442	(81)
$SnBr_4$		−0.354	(81)
$SnSO_4$	18	−0.29	(73)
$Sn(CH_3)_4$		−0.218	(82)
$Sn(C_2H_5)_4$		−0.138	(82)
$Sn(C_4H_9)_4$		−0.085	(82)

TABLE 3.—(*Continued*)

Formula	t	χ	Lit.
$SnO(OH)(CH_3)$		− 0.324	(84)
PbO	18	− 0.13	(73)
Pb_3O_4	18	− 0.24	(73)
PbF_2	16	− 0.24	(73)
$PbCl_2$	15	− 0.32	(73)
$PbBr_2$	20	− 0.28	(73)
PbI_2	19	− 0.33	(73)
$Pb(NO_3)_2$		− 0.248	(112)
$Th(NO_3)_4$		− 0.14	(73)
$InCl_3$	18	− 0.39	(73)
In_2S_3	20	− 0.19	(73)
$TlCl$	20	− 0.19	(73)
$TlCl_3$	20	− 0.23	(73)
Tl_2SO_4	20	− 0.25	(73)
$TlNO_3$	20	− 0.20	(73)
ZnO		− 0.362	(32)
$Zn(OH)_2$		− 0.487	(127)
$ZnCl_2$	22	− 0.47Aq	(62)
$ZnBr_2$	19	− 0.40	(73)
$ZnSO_4.7H_2O$		− 0.48	(71)
CdO	15	− 0.30	(73)
$CdCl_2$	18	− 0.32	(73)
$CdBr_2$	18	− 0.38	(73)
CdI_2	18	− 0.32	(73)
HgO	16	− 0.24	(73)
$HgCl$	19	− 0.23	(73)
$HgCl_2$	17	− 0.19	(73)
$HgBr_2$	15	− 0.30	(73)
HgI_2	17	− 0.33	(73)
HgS	16	− 0.23	(73)
$Hg(CH_3)_2$		−46	(83)
$Hg(C_2H_5)_2$		−40.8	(83)
$Hg(C_4H_9)_2$		−36.1	(83)
$Hg(C_5H_{11})_2$		−35.4	(83)
CuO		3.8	(127)
Cu_2O		1.2	(127)
$Cu(OH)_2.CuO$		5.0	(127)
$CuCl_2$	−159	19.50	(55)
	19	9.10	(55)
	503	3.82	(55)
$CuCl_2.2H_2O$	17	8.35	(36)
$CuBr_2$	−177	2.88	(55)
	− 99	3.30	(55)
	31	3.10	(55)
	282	2.25	(55)
CuS	17	− 0.20	(73)
Cu_2S	18	− 0.18	(73)
$CuSO_4$		8.6	(36)
$CuSO_4.H_2O$		8.6	(36)
$CuSO_4.5H_2O$		5.9	(36)
Cu_2Se	17	− 0.19	(73)
$Cu(NO_3)_2.6H_2O$		5.50	(32)
$CuCl_2.2NH_4Cl$	17	5.23	(36)
$CuCl_2.2NH_4Cl.2H_2O$	17	4.95	(36)
Cu_3P_2	18	− 0.23	(73)
$Cu(CH_3CO_2)_2.H_2O$		3.27	(32)
$AgCl$	17	− 0.35	(73)
$AgBr$	19	− 0.33	(73)
AgI	19	− 0.37	(73)
$AuCl_3$	21	0.43	(73)
$PtCl_2$	15	− 0.024	(73)
$PtCl_4$	22	0.0Aq	(62)
$(NH_4)_2PtCl_6$		− 0.42	(36)

Formula	t	χ	Lit.
MnO	−189	89.9	(53)
	21	75.9	(53)
	419	51.8	(53)
MnO_2	−186	75.9	(53)
	21	38.4	(53)
	503	22.7	(53)
Mn_2O_3	−184	150.0	(53)
	21	69.0	(53)
	388	42.9	(53)
	928	29.5	(53)
Mn_3O_4	−175	126.0	(53)
	20	55.8	(53)
	497	34.9	(53)
	1081	25.6	(53)
$Mn(OH)_2$		49	(92)
MnF_2	18	155Aq	(65)
$MnCl_2$	−179	393	(55)
	24	107.0	(55)
	556	35.8	(55)
$MnBr_2$	18	68Aq	(65)
MnI_2	18	47	(65)
MnS	10	44.32	(116)
$MnSO_4$	−178	261.0	(53)
	24	88.5	(53)
	747	30.0	(53)
Mn_5N_2		15 000	(55)
$Mn(NO_3)_2.6H_2O$		45.5	(32)
$MnSO_4.(NH_4)_2SO_4.6H_2O$	−258.26	756	(57)
	−252.76	547	(57)
	−195.74	141.4	(57)
	−104.0	65.6	(57)
	16.6	37.8	(57)
$MnPO_4$		69Aq	(117)
Fe_2O_3	18	20.6	(53)
$Fe(OH)_3$		157	(73)
$FeF_3.3H_2O$	−162	55.0	(55)
	17	47.3	(55)
	99	42.8	(55)
$FeCl_2$	−182	449	(55)
	17	101.2	(55)
	473	36.8	(55)
$FeCl_2.4H_2O$	−181	210.0	(55)
	19	60.1	(55)
	65	52.3	(55)
$FeCl_3$	−174	252.0	(55)
	20	86.2	(55)
	135	60.9	(55)
$FeBr_3$	18	48Aq	(65)
FeI_2	18	40Aq	(65)
$FeSO_4$	−258.7	335	(57)
	−253.0	402	(57)
	−195.8	200.4	(57)
	−103.5	107.2	(57)
	17.1	67.6	(57)
	19	74.2	(55)
	642	24.0	(55)
$FeSO_4.7H_2O$	−259.17	757	(57)
	−252.77	555	(57)
	−195.65	154.5	(57)
	16.5	41.5	(57)
$Fe_2(SO_4)_3$	−177	133.2	(55)
	23	57.3	(55)
	658	20.9	(55)

TABLE 3.—(*Continued*)

Formula	t	χ	Lit.
$Fe(NO_3)_3.6H_2O$		31.3	(32)
$FeF_3.NH_4F$		66.1	(36)
$FeF_3.2NH_4F.H_2O$		73	(36)
$FeCl_3.2NH_4Cl.H_2O$	−199	132.7	(55)
	−100	74.3	(55)
	16	47.3	(55)
$FeSO_4.(NH_4)_2SO_4$	18	43Aq	(65)
$FeSO_4.(NH_4)_2SO_4.6H_2O$	−258.6	547	(57)
	−252.8	413	(57)
	−196.0	121.6	(57)
	17.2	32.6	(57)
$Fe_2(SO_4)_3.(NH_4)_2SO_4$	−178	151.9	(55)
	28	50.5	(55)
	410	23.0	(55)
$Fe_2(SO_4)_3.(NH_4)_2SO_4.$ $24H_2O$	−258.4	598	(77)
	−253	432	(77)
	−196	114.7	(77)
	17	30.4	(77)
$Fe(CO)_5$	19	− 0.40	(80)
$Cu[Fe(CN)_5NO]$		5.73	(45)
$Cu[Fe(CN)_5NO].2H_2O$		4.57	(45)
CoO		74.5	(127)
Co_2O_3		34.3	(127)
Co_3O_4		39 to 43.6	(127)
CoF_2	18	103Aq	(65)
$CoCl_2$	−180	403.0	(55)
	25	90.5	(55)
	628	26.5	(55)
$CoBr_2$		46.8Aq	(33)
CoI_2	18	32Aq	(65)
$CoSO_4$	−258.33	462	(57)
	−252.65	379	(57)
	−195.83	169.7	(57)
	−103.33	97.0	(57)
	16.6	62.2	(57)
	22	59.6	(55)
	707	18.8	(55)
$CoSO_4.H_2O$		53.6	(36)
$CoSO_4.7H_2O$	−258.34	535.9	(57)
	−252.7	403.0	(57)
	−195.62	126.5	(57)
	−103.6	61.6	(57)
	19.9	37.0	(57)
$CoH_2(SO_4)_2.6H_2O$		64	(34)
$Co(NO_3)_2.6H_2O$		33.1	(32)
$[Co(NH_3)_5H_2O](NO_3)_3.H_2O$		0.112	(36)
$[(Co(NH_3)_5)_2O](NO_3)_4.$ $2H_2O$		− 0.092	(36)
$[Co(NH_3)_4Cl_2]Cl$		− 0.022	(36)
$[Co(NH_3)_5Cl]Cl_2$		− 0.295	(36)
$[Co(NH_3)_6]Cl_3$		− 0.38	(36)
$[Co(NH_3)_5H_2O]Cl_3$		− 0.306	(36)
$[Co(NH_3)_6]I_3$		− 0.10	(36)
$CoSO_4.(NH_4)_2SO_4$	19	37Aq	(93)
$CoSO_4.(NH_4)_2SO_4.6H_2O$	−258.32	322	(57)
	−252.8	241	(57)
	−195.82	78.4	(57)
	27.7	24.6	(57)
$[Co(NH_3)_5HSO_4]_2SO_4$		− 1.33	(36)
$[Co(NH_3)_6]_2(SO_4)_3.5H_2O$		− 0.315	(36)
$Co[CH(COCH_3)_2]_2$		30.2	(36)

Formula	t	χ	Lit.
$Co(C_5H_7O_2)_3$	−134	1.157	(55)
	− 20	0.644	(55)
	28	0.569	(55)
$[Co(NH_3)_5H_2O]_2(C_2O_4)_3$		− 0.218	(36)
$CoSO_4.CuSO_4.6H_2O$		26	(34)
NiO		53.7	(127)
$Ni(OH)_2$		48.3	(127)
NiF_2	18	44Aq	(65)
$NiCl_2$	−163	265.7	(55)
	24	44.7	(55)
	847	10.0	(55)
$NiBr_2$	18	19Aq	(65)
$NiSO_4$	−258.4	80.6	(57)
	−252.77	81.7	(57)
	−195.7	62.8	(57)
	−103.9	39.9	(57)
	15.9	26.7	(57)
	24	27.1	(55)
	343	15.0	(55)
	763	10.2	(55)
$NiSO_4.H_2O$		24.1	(36)
$NiSO_4.6H_2O$		15.6	(36)
$NiSO_4.7H_2O$	−258.5	294.0	(57)
	−252.77	222.0	(57)
	−195.81	77.3	(57)
	−103.5	34.8	(57)
	19.1	16.0	(57)
$NiSO_4.(NH_4)_2SO_4.6H_2O$	−258.6	207.5	(57)
	−252.8	150.4	(57)
	−195.95	39.5	(57)
	−103.6	18.93	(57)
	13.4	10.68	(57)
$Ni(NO_3)_2.6H_2O$		13.6	(32)
$Ni(CO)_4$	19	− 0.481	(80)
CrO_3	17	0.51	(53)
	142	0.51	(53)
Cr_2O_3	−186	20.1	(53)
	− 64	22.2	(53)
	18	25.5	(53)
	117	25.6	(53)
	797	16.4	(53)
	1335	12.6	(53)
$Cr_2O_3.4H_2O$	−183	110.5	(55)
	− 88	61.4	(55)
	16	41.1	(55)
$Cr_2O_3.7H_2O$	−164	93.5	(55)
	− 68	54.9	(55)
	19	40.0	(55)
$Cr(OH)_2$		48.5Aq	(92)
H_2CrO_4	17	0.70	(73)
$Cr_2(OH)_6.H_2O$		45.5	(127)
$CrCl_2$		84Aq	(117)
$CrCl_3$	−168	176.5	(52)
	19	44.3	(52)
	806	10.3	(52)
Cr_2OCl_4 (violet)		46Aq	(15)
(green)		43Aq	(15)
CrS	20	28.4	(116)
Cr_2S_3	18	23.3	(116)
Cr_3S_4	16	33.3	(116)
$CrSO_4$		66Aq	(15)
$Cr_2O(SO_4)_2$ (violet)		38Aq	(15)
(green)		36Aq	(15)
$Cr_2(SO_4)_3$	−180	97.0	(55)

TABLE 3.—(*Continued*)

Formula	t	χ	Lit.
$Cr_2(SO_4)_3$.—(*Continued*)	21	29.5	(55)
	650	9.7	(55)
$Cr_2(SO_4)_3.9H_2O$	17	23.2	(55)
$Cr(NO_3)_3.9H_2O$		13.75	(32)
$[Cr(NH_3)_4.C_2O_4][Cr(NH_3)_2.(C_2O_4)_2].3H_2O$		24.4	(36)
$[Cr(NH_3)_6][Cr(C_2O_4)_3].3H_2O$		24.4	(36)
$[Cr(NH_3)_6][Co(C_2O_4)_3].3H_2O$		15.5	(36)
$[Cr(C_2O_4)_3][Co(NH_3)_6].3H_2O$		11.65	(36)
MoO_2	20	0.33	(116)
MoO_3	20	0.88	(116)
Mo_2O_3	16	− 0.35	(73)
Mo_3O_8	16	0.30	(116)
H_2MoO_4	14	− 0.015	(73)
MoS_3	16	− 0.33	(73)
WO_3	15	0.81	(116)
H_2WO_4	18	− 1.1	(73)
UO_2	17	7.5	(116)
UO_3	16	1.08	(116)
U_3O_8	15	0.95	(116)
UCl_4	19	− 0.40	(73)
$UO_2(NO_3)_2$	15	− 0.44	(73)
VO	15	50.1	(116)
VO_2	13	3.73	(116)
V_2O_3	15	13.9	(116)
V_2O_5	15	0.85	(116)
VS	16	7.22	(116)
V_2S_3	16	8.95	(116)
V_2S_5	15	12.6	(116)
NH_4VO_3	15	− 0.12	(73)
Cb_2O_5	20	− 0.10	(73)
$H_4Ta_4O_7$	20	0.29	(73)
B_2O_3	14	− 0.55	(73)
H_3BO_3		− 0.52	(71)
BN	15	0.0	(73)
Al_2O_3		− 0.098	(127)
$Al_2O_3.2H_2O$		− 0.337	(127)
$AlCl_3$	19	− 0.60	(73)
$AlBr_3$	19	− 0.32	(73)
$Al_2(SO_4)_3$	18	− 0.48	(73)
Sc_2O_3		− 0.018	(71)
$Sc_2(SO_4)_3$		− 0.33	(114)
$Sc(NO_3)_3$	21	0.0	(73)
$Sc_2(C_2O_4)_3$		− 0.25	(71)
Y_2O_3	22	0.53	(124)
YCl_3	17	20	(73)
$Y_2(SO_4)_3$		− 0.24	(114)
$Y_2(CO_3)_3.3H_2O$	20	9.2	(73)
La_2O_3	24	− 0.40	(124)
$LaCl_3$	15	5.6	(73)
$La_2(SO_4)_3$		− 0.30	(114)
$La(NO_3)_3.2NH_4NO_3$	15	− 0.29	(73)
CeO_2		0.39	(71)
$CeCl_3$	19	6.1	(73)
$CeBr_3$	18	6.0Aq	(27)
$Ce_2(SO_4)_3$		7.8	(114)
$Ce(NO_3)_3.2NH_4NO_3$	16	4.2	(73)
$Ce(CO_3)_2$	20	3.4	(73)
$Ce_2(CO_3)_3$	15	9.0	(73)
Pr_2O_3		15.6	(76)
Pr_4O_7	15	16	(73)
$PrCl_3$	19	17	(73)
$Pr_2(SO_4)_3$		13.7	(76)
Neodymium oxide	23	29.3	(124)
	179	19.8	(124)
	283	16.6	(124)
Nd_2O_3		30.3	(114)
$Nd_2(SO_4)_3$		18.3	(114)
$Nd(NO_3)_3.2NH_4NO_3$	18	11	(73)
$Nd(NO_3)_3.2NH_4NO_3.4H_2O$	18	8.7	(73)
$Nd_2(C_2O_4)_3$		14.7	(76)
Sa_2O_3	22	6.02	(124)
	102	5.93	(124)
	270	5.98	(124)
$SaSO_4$		3.43	(36)
$SaSO_4.8H_2O$		2.6	(36)
Gd_2O_3	20	130.1	(124)
	180	85.5	(124)
	280	67.8	(124)
$GdCl_3$	18	91	(27)
$Gd_2(SO_4)_3$		92.6	(36)
$Gd_2(SO_4)_3.8H_2O$	−259.2	1468	(78)
	−256.1	1229	(78)
	−252.8	1039	(78)
	17	72.9	(78)
$Gd_2(C_2O_4)_3$		25	(128)
$Gd(C_2H_5SO_4)_3.9H_2O$	−258.5	699	(58)
	−253	154	(58)
	−104	59.1	(58)
	18	34.3	(58)
Dy_2O_3	−259	2334	(77)
	−253	1915	(77)
	−103	375	(77)
	16	229	(77)
	180	153.9	(124)
	300	122.6	(124)
Ho_2O_3		243	(129)
$HoCl_3$		172	(129)
$Ho(NO_3)_3$		123.6	(129)
Er_2O_3	20	189.1	(124)
	180	124.4	(124)
	280	102.2	(124)
$ErCl_3$	18	114Aq	(27)
$Er_2(SO_4)_3$		118	(115)
$Er_2(C_2O_4)_3$		94	(115)
Yb_2O_3		38	(73)
$YbCl_3$		25Aq	(27)
HfO_2		− 0.110	(73)
BeO	16	0.0	(73)
$Be(OH)_2$		− 0.537	(84)
$BeCl_2$	17	− 0.60	(73)
$BeSO_4$	18	− 0.46	(73)
$BeSO_4.4H_2O$	17	− 0.51	(73)
$BeCO_3.2BeO$	15	− 0.34	(73)
MgO	17	− 0.25	(73)
$MgCl_2$	18	− 0.58	(73)
$MgCl_2.6H_2O$	18	− 0.57	(73)
$MgBr_2$	20	− 0.57	(73)
$MgSO_4$		− 0.45Aq	(103)
$MgSO_4.7H_2O$		− 0.551	(84)
$MgCO_3$		− 0.51	(73)
$MgCO_3.3H_2O$		− 0.525	(84)
$Mg(C_2H_5SO_2)_2.2H_2O$		− 0.525	(84)

TABLE 3.—(*Continued*)

Formula	t	χ	Lit.
CaO	16	− 0.27	(73)
$Ca(OH)_2$	16	− 0.39	(73)
CaF_2		− 0.360	(84)
$CaCl_2$	17	− 0.49	(73)
$CaCl_2.6H_2O$	17	− 0.54	(73)
$CaSO_4$		− 0.364	(84)
$CaSO_4.H_2O$		− 0.384	(84)
$CaCO_3$		− 0.382	(84)
SrO	20	− 0.060	(73)
SrF_2		− 0.296	(84)
$SrCl_2$	20	− 0.56	(73)
$SrBr_2$	19	− 0.39	(73)
SrI_2	19	− 0.44	(73)
$SrSO_4$		− 0.315	(84)
$SrCO_3$		− 0.316	(84)
BaO	20	− 0.13	(73)
$Ba(OH)_2$	18	− 0.32	(73)
$Ba(OH)_2.8H_2O$		− 0.497	(83)
BaF_2		− 0.291	(83)
$BaCl_2$		− 0.41	(73)
$BaCl_2.2H_2O$		− 0.368	(32)
$BaBr_2$		− 0.39	(73)
$BaBr_2.2H_2O$		− 0.371	(32)
BaI_2	22	− 0.39Aq	(62)
$BaI_2.2H_2O$	19	− 0.38	(73)
BaS	18	− 0.32	(73)
$BaSO_4$		− 0.306	(84)
$BaS_2O_6.2H_2O$		− 0.359	(84)
$Ba(NO_3)_2$		− 0.254	(84)
$Ba_3(AsO_3)_2$		− 0.280	(84)
$BaCO_3$		− 0.298	(84)
$Ba(MnO_4)_2$		10.1	(116)
Li_2O	20	− 0.57	(73)
$LiCl$		− 0.573	(83)
Li_2SO_4	15	− 0.38	(73)
$Li_2SO_4.H_2O$	17	− 0.43	(73)
$LiNO_3$	19	− 0.48	(73)
Li_2CO_3		− 0.413	(83)
$NaOH$	17	− 0.59	(73)
NaF	21	− 0.51	(73)
$NaCl$	−150	− 0.501	(55)
	18	− 0.499	(55)
	362	− 0.499	(55)
	933	− 0.508	(55)
$NaBr$	18	− 0.47	(73)
$NaI.2H_2O$		− 0.402	(32)
$Na_2SO_3.7H_2O$		− 0.462	(84)
$Na_2SO_4.10H_2O$		− 0.86	(71)
$Na_2S_2O_3$		− 0.391	(84)
$NaNO_3$		− 0.28	(71)
NaH_2PO_2		− 0.381	(84)
Na_2HPO_3		− 0.451	(84)
Na_2HPO_4		− 0.399	(84)
$AsO(ONa)_3.12H_2O$		− 0.566	(84)
Na_2CO_3	17	− 0.24	(73)
$Na_2CO_3.10H_2O$	17	− 0.58	(73)
$NaHCO_3$		− 0.21	(71)
$NaC_2H_3O_2.3H_2O$		− 0.50	(71)
$CH_3AsO(ONa)_2.H_2O$		− 0.529	(84)
$SnO(ONa)_2.3H_2O$		− 0.370	(84)

Formula	t	χ	Lit.
$NaCl.CuCl_2$	17	6.48	(36)
$Na_2B_4O_7.10H_2O$		− 0.59	(71)
KOH	22	− 0.33Aq	(62)
KHF_2		− 0.428	(32)
KCl		− 0.516	(83)
$KClO_3$		− 0.30	(71)
KBr		− 0.377	(32)
KI		− 0.422	(32)
K_2SO_4		− 0.403	(83)
$K_2S_2O_8$		− 0.371	(84)
$K_2S_4O_6$		− 0.412	(84)
KNO_3		− 0.326	(83)
$(KSO_3)_2NOH$		− 0.401	(84)
K_2CO_3		− 0.488	(32)
$(COOK)_2.H_2O$		− 0.77	(71)
$[CH(OH)COOK]_2.0.5H_2O$		− 1.10	(71)
$KCNO$		− 0.465	(85)
$K_2H(C_3N_3O_3).H_2O$		− 0.488	(85)
$SO_3KCH(NH_2)SO_3H$		− 0.424	(84)
$KCl.CuCl_2$	17	6.03	(36)
$2KCl.CuCl_2$	17	4.28	(36)
$2KCl.CuCl_2.2H_2O$	17	4.30	(36)
K_2PtCl_4		− 0.356	(36)
K_2PtCl_6		− 0.393	(36)
$K_2Pt(C_2O_4)_2.2H_2O$		− 0.31	(36)
$KMnO_4$	−170	0.179	(55)
	21	0.175	(55)
	95	0.175	(55)
	162	0.184	(55)
$K_3Fe(CN)_6$	−148	14.43	(55)
	− 70	9.96	(55)
	21	7.08	(55)
$K_4Fe(CN)_6.3H_2O$		− 0.420	(80)
$K_2SO_4.CoSO_4.6H_2O$	−258.36	321	(57)
	−252.68	243.5	(57)
	−195.73	75.1	(57)
	−103.8	38.7	(57)
	17.9	23.4	(57)
$K_2Cr_2O_7$		0.129	(32)
$K_2SO_4.Cr_2(SO_4)_3.24H_2O$		11.5	(32)
$K_2SO_4.Al_2(SO_4)_3$	17	− 0.470	(55)
	− 84	− 0.476	(55)
	−159.7	− 0.480	(55)
$K_2SO_4.Al_2(SO_4)_3.24H_2O$		− 0.579	(112)
$RbCl$		− 0.327	(83)
Rb_2SO_4		− 0.331	(83)
$RbNO_3$		− 0.281	(83)
Rb_2CO_3		− 0.321	(83)
$Rb_2SO_4.CoSO_4.6H_2O$	−258.44	268.0	(57)
	−252.77	201.0	(57)
	−195.67	64.6	(57)
	−103.65	34.1	(57)
	14.9	21.0	(57)
$CsCl$		− 0.363	(83)
Cs_2SO_4		− 0.322	(83)
$CsNO_3$		− 0.412	(83)
Cs_2CO_3		− 0.320	(83)
$Cs_2SO_4.Al_2(SO_4)_3$	15	− 0.51	(73)
$Cs_2SO_4.Al_2(SO_4)_3.24H_2O$	14	− 0.49	(73)

TABLE 4.—SPECIFIC SUSCEPTIBILITY (χ): PURE ORGANIC COMPOUNDS

Centigrade temperature; where unindicated, room temperature is to be understood; unit of $\chi = 10^{-6}$ cgsm

℃-Table, ℃-Arrangement; *v.* Vol. III, p. viii

Formula	Name (and temperature)	χ	Lit.
CBr_4	Carbon tetrabromide	−0.293	(82)
CCl_3NO_2	Trichloronitromethane	−0.458	(82)
CCl_4	Carbon tetrachloride	−0.429	(82)
CI_4	Carbon tetraiodide	−0.261	(82)
CN_4O_8	Tetranitromethane	−0.223	(82)
$CHBr_3$	Bromoform	−0.316	(82)
$CHCl_3$	Chloroform	−0.488	(82)
CH_2Br_2	Methylene bromide	−0.379	(82)
CH_2Cl_2	Methylene chloride	−0.549	(81)
CH_2I_2	Methylene iodide	−0.349	(82)
CH_2O	Formaldehyde	−0.62	(71)
CH_2O_2	Formic acid	−0.432	(81)
CH_3Br	Methyl bromide	−0.603	(81)
CH_3Cl	Methyl chloride	−0.633	(81)
CH_3I	Methyl iodide	−0.403	(81)
CH_3NO	Formamide	−0.486	(82)
CH_4	Methane	−2.5	(30, 31)
CH_4N_2O	Urea	−0.560	(82)
CH_4O	Methyl alcohol (−3°)	−0.65	(55, 56)
CH_5N	Methylamine	−0.870	(81)
$C_2Br_2Cl_4$	1, 2-Dibromotetrachloroethane	−0.387	(82)
$C_2Br_2I_2$	1, 2-Dibromodiiodoethylene	−0.320	(82)
C_2Br_4	Tetrabromoethylene	−0.334	(82)
C_2Br_6	Hexabromoethane	−0.294	(82)
C_2Cl_4	Tetrachloroethylene	−0.508	(81, 82)
C_2Cl_6	Hexachloroethane	−0.476	(82)
C_2I_4	Tetraiodoethylene	−0.309	(82)
C_2N_2	Cyanogen	−0.415	(81)
C_2HCl_3O	Chloral	−0.459	(82)
C_2HCl_5	Pentachloroethane	−0.490	(82)
$C_2H_2BrFO_2$	Fluorobromoacetic acid	−0.379	(82)
$C_2H_2Br_2$	1, 2-Dibromoethylene	−0.386	(82)
$C_2H_2Br_2Cl_2$	1, 2-Dichloro-1, 2-dibromoethane	−0.423	(82)
$C_2H_2Br_2F_2$	1-Difluoro-2-dibromoethane	−0.382	(82)
$C_2H_2Br_4$	1, 1, 2, 2-Tetrabromoethane	−0.357	(82)
$C_2H_2Cl_2$	1, 2-Dichloroethylene	−0.521	(82)
$C_2H_2Cl_4$	1, 1, 2, 2-Tetrachloroethane	−0.535	(82)
$C_2H_3Br_2F$	1, 2-Dibromo-2-fluoroethane	−0.379	(82)
$C_2H_3F_2NO$	Difluoroacetamide	−0.433	(82)
C_2H_4	Ethylene	−1.6	(30, 31)
$C_2H_4Br_2$	Ethylene bromide	−0.422	(81)
$C_2H_4Cl_2$	Ethylene chloride	−0.602	(81)
$C_2H_4Cl_2$	Ethylidene chloride	−0.580	(81)
$C_2H_4F_2O$	Difluoroethanol	−0.503	(82)
$C_2H_4I_2$	Ethylene iodide	−0.381	(82)
$C_2H_4N_2O_2$	Oxamide	−0.443	(82)
C_2H_4O	Acetaldehyde	−0.502	(81)
$C_2H_4O_2$	Acetic acid	−0.526	(81)
$C_2H_4O_2$	Methyl formate	−0.518	(82)
C_2H_5Br	Ethyl bromide	−0.489	(81)
C_2H_5I	Ethyl iodide	−0.679	(71)
C_2H_5NO	Acetamide	−0.577	(82)
$C_2H_5NO_2$	Nitroethane	−0.472	(82)
C_2H_6O	Ethyl alcohol	−0.744	(81)
C_2H_6O	Methyl ether	−0.716	(61)
$C_2H_6O_2$	Glycol	−0.624	(82)
$C_2H_6O_4S$	Dimethyl sulfate	−0.493	(81)
C_2H_6S	Dimethyl sulfide	−0.723	(81)
$C_2H_7AsO_2$	Cacodylic acid	−0.579	(84)
C_2H_7NO	Ethylhydroxylamine	−0.704	(82)
$C_2H_7O_4P$	Ethyl phosphate	−0.539	(84)
$C_3H_3N_3O_3$	Cyanuric acid	−0.490	(85)
$C_3H_3N_3O_3$	Cyamelide	−0.435	(85)
$C_3H_5Br_3$	1, 2, 3-Tribromopropane	−0.420	(82)
C_3H_5ClO	Chloroacetone	−0.550	(81)
C_3H_5NO	Ethyl isocyanate	−0.642	(85)
$C_3H_6Cl_2O$	1, 3-Dichloro-2-hydroxypropane	−0.621	(81)
C_3H_6O	*n*-Propionaldehyde	−0.585	(81)
C_3H_6O	Acetone	−0.581	(81)
$C_3H_6O_2$	Propionic acid	−0.587	(81)
$C_3H_6O_2$	Ethyl formate	−0.581	(82)
$C_3H_6O_2$	Methyl acetate	−0.590	(82)
C_3H_7Br	*n*-Propyl bromide	−0.527	(81)
C_3H_7Br	Isopropyl bromide	−0.529	(81)
C_3H_7Cl	Propyl chloride	−0.710	(81)
$C_3H_7ClO_2$	1-Chloro-2, 3-dihydroxypropane	−0.604	(81)
C_3H_8O	Propyl alcohol	−0.766	(81)
$C_3H_8O_2$	Methylal	−0.621	(82)
$C_3H_8O_3$	Glycerol	−0.538	(71)
$C_3H_{10}N_2$	Propylenediamine	−0.784	(81)
C_4HI_4N	Tetraiodopyrrole	−0.331	(82)
$C_4H_2O_3$	Maleic anhydride	−0.365	(45, 46)
$C_4H_4O_3$	Succinic anhydride	−0.475	(45, 46)
$C_4H_4O_4$	Maleic acid	−0.427	(45, 46)
$C_4H_4O_4$	Fumaric acid	−0.426	(45, 46)
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	−0.520	(82)
$C_4H_5Br_3O_2$	Ethyl tribromoacetate	−0.368	(82)
$C_4H_5NO_2$	Succinimide	−0.477	(82)
$C_4H_6O_3$	Acetic anhydride	−0.517	(82)
$C_4H_6O_4$	Succinic acid	−0.461	(45, 46)
$C_4H_6O_4$	Dimethyl oxalate	−0.472	(82)
$C_4H_7BrO_2$	Ethyl bromoacetate	−0.496	(81)
$C_4H_7ClO_2$	Ethyl chloroacetate	−0.590	(81)
$C_4H_7IO_2$	Ethyl iodoacetate	−0.456	(81)
C_4H_7N	Propyl cyanide	−0.714	(81)
$C_4H_8N_2O_2$	Dimethyloxamide	−0.544	(82)
C_4H_8O	Butyraldehyde	−0.635	(81)
C_4H_8O	Methyl ethyl ketone	−0.633	(82)
$C_4H_8O_2$	*n*-Butyric acid	−0.632	(82)
$C_4H_8O_2$	Isobutyric acid	−0.646	(81)
$C_4H_8O_2$	Ethyl acetate (−149°)	−0.581	(55, 56)
	(−6°)	−0.607	(55, 56)
$C_4H_8O_2$	Methyl propionate	−0.628	(82)
C_4H_9NO	Isobutyraldoxime	−0.642	(82)
$C_4H_{10}N_2O$	Nitrosodiethylamine	−0.593	(82)
$C_4H_{10}O$	*n*-Butyl alcohol	−0.743	(71)
$C_4H_{10}O$	Isobutyl alcohol	−0.798	(81)
$C_4H_{10}O$	*tert.*-Butyl alcohol	−0.800	(81)
$C_4H_{10}O$	Ethyl ether	−0.766	(71)
$C_4H_{10}OS$	Ethyl sulfine	−0.631	(84)
$C_4H_{10}O_3S$	Ethyl sulfite	−0.546	(84)
$C_4H_{10}O_3S$	Ethylsulfone ethyl ether	−0.592	(84)
$C_4H_{10}O_4S$	Diethyl sulfate	−0.563	(84)
$C_4H_{10}S$	Diethyl sulfide	−0.753	(81)
$C_4H_{11}N$	Diethylamine	−0.835	(81, 82)
$C_4H_{11}N$	Isobutylamine	−0.843	(81)
$C_4H_{12}As_2$	Cacodyl	−0.476	(84)
$C_5H_4O_2$	Furfural	−0.492	(82)
C_5H_5N	Pyridine	−0.623	(82)
$C_5H_7NO_2$	Ethyl cyanoacetate	−0.595	(81)

TABLE 4.—(*Continued*)

Formula	Name (and temperature)	χ	Lit.
$C_5H_8O_2$	Acetylacetone	−0.561	(82)
$C_5H_8O_2$	Allyl acetate	−0.566	(81)
$C_5H_8O_4$	Dimethyl malonate	−0.520	(82)
C_5H_{10}	Isoamylene	−0.766	(71)
C_5H_{10}	Trimethylethylene	−0.773	(81)
$C_5H_{10}Br_2$	Amylene bromide	−0.498	(81)
$C_5H_{10}Cl_2$	Amylene chloride	−0.675	(81)
$C_5H_{10}Cl_2$	Amylidene chloride	−0.662	(81)
$C_5H_{10}N_2O$	Nitrosopiperidine	−0.555	(82)
$C_5H_{10}O$	Isovaleraldehyde	−0.668	(82)
$C_5H_{10}O$	Methyl propyl ketone	−0.668	(82)
$C_5H_{10}O_2$	Isovaleric acid	−0.663	(81)
$C_5H_{10}O_3$	Ethyl lactate	−0.615	(82)
$C_5H_{11}Br$	Isoamyl bromide	−0.587	(81)
$C_5H_{11}Cl$	Isoamyl chloride	−0.741	(81)
$C_5H_{11}N$	Piperidine	−0.755	(81)
$C_5H_{11}NO_3$	Amyl nitrate	−0.574	(81)
$C_5H_{12}O$	*n*-Amyl alcohol	−0.766	(71)
$C_5H_{12}O$	Isoamyl alcohol	−0.799	(81)
$C_5H_{12}O$	*tert.*-Amyl alcohol	−0.804	(81)
$C_5H_{12}O_2$	Acetal	−0.825	(82)
$C_5H_{13}N$	Isoamylamine	−0.848	(81)
$C_6Cl_4O_2$	Chloranil	−0.458	(82)
C_6Cl_6	Hexachlorobenzene	−0.518	(82)
$C_6O_6.8H_2O$	Triquinoyl	−0.426	(82)
C_6HBr_5O	Pentabromophenol	−0.397	(82)
$C_6H_2Cl_6O_3$	Hexachlorohexanetrione	−0.433	(82)
$C_6H_3Br_2NO_3$	Dibromo-4-nitrophenol	−0.564	(82)
$C_6H_3Cl_3$	Trichlorobenzene	−0.587	(81)
$C_6H_3N_3O_6$	1, 3, 5-Trinitrobenzene	−0.352	(82)
$C_6H_4N_2O_4$	*m*-Dinitrobenzene	−0.398	(82)
$C_6H_4N_2O_5$	2, 4-Dinitrophenol	−0.397	(82)
$C_6H_4N_2O_6$	Dinitroresorcinol	−0.312	(82)
$C_6H_4O_2$	Quinone	−0.382	(82)
C_6H_5Br	Bromobenzene (−30°)	−0.514	(80)
	(−20°)	−0.540	(80)
C_6H_5Cl	Chlorobenzene	−0.639	(81)
	(−50°)	−0.629	(80)
	(−30°)	−0.664	(80)
$C_6H_5Cl_5O_2$	Pentachlorohexanedione	−0.452	(82)
C_6H_5F	Fluorobenzene	−0.608	(82)
C_6H_5I	Iodobenzene	−0.471	(81)
C_6H_5NO	Nitrosobenzene	−0.514	(82)
$C_6H_5NO_2$	Nitrobenzene (−160°)	−0.455	(80)
	(0°)	−0.439	(80)
	(20°)	−0.499	(80)
$C_6H_5NO_2$	Quinonoxime	−0.409	(82)
$C_6H_5NO_3$	*p*-Nitrophenol	−0.482	(82)
C_6H_6	Benzene (16.8°)	−0.712	(55, 56)
C_6H_6O	Phenol	−0.648	(81)
$C_6H_6O_2$	Resorcinol	−0.617	(82)
$C_6H_6O_3$	Phloroglucinol	−0.582	(82)
C_6H_7N	Aniline (−10°)	−0.661	(80)
	(10°)	−0.692	(80)
C_6H_7NO	Phenylhydroxylamine	−0.625	(82)
C_6H_8	1, 3-Cyclohexadiene	−0.607	(85)
C_6H_8	1, 4-Cyclohexadiene	−0.608	(85)
$C_6H_8N_2$	Phenylhydrazine (20°)	−0.675	(80)
	(10°)	−0.720	(80)
$C_6H_9BiO_6$	Bismuth acetate	−0.090	(44)
$C_6H_9NO_2$	Ethylsuccinimide	−0.566	(82)
C_6H_{10}	Cyclohexene	−0.711	(85)
C_6H_{10}	Diallyl	−0.671	(81)
$C_6H_{10}O$	Cyclohexenol	−0.653	(85)
$C_6H_{10}O$	Cyclohexanone	−0.648	(82)
$C_6H_{10}O_2$	Diethanolacetylene	−0.660	(82)
$C_6H_{10}O_2$	Dimethylketotetrahydrofurfurane	−0.600	(82)
$C_6H_{10}O_2$	Methylacetylacetone	−0.569	(82)
$C_6H_{10}O_3$	Ethyl acetoacetate (old)	−0.556	(81)
	(fresh)	−0.576	(81)
$C_6H_{10}O_4$	Diethyl oxalate	−0.555	(82)
C_6H_{12}	Hexene	−0.780	(85)
C_6H_{12}	Cyclohexane	−0.810	(85)
$C_6H_{12}O$	Methyl butyl ketone	−0.690	(82)
$C_6H_{12}O$	Methyl isobutyl ketone	−0.697	(81)
$C_6H_{12}O$	Methyl *tert.*-butyl ketone	−0.703	(81)
$C_6H_{12}O$	Cyclohexanol	−0.727	(85)
$C_6H_{12}O_2$	Isobutyl acetate	−0.680	(81)
$C_6H_{12}O_3$	Methyl α-methoxyisobutyrate	−0.620	(82)
$C_6H_{12}O_3$	Paraldehyde	−0.652	(81)
C_6H_{14}	Hexane	−0.888	(81)
$C_6H_{14}O$	Hexyl alcohol	−0.766	(71)
$C_6H_{14}S$	Propyl sulfide	−0.777	(81)
$C_6H_{15}OP$	Triethylphosphine oxide	−0.683	(84)
$C_6H_{15}O_3P$	Triethyl phosphite	−0.631	(84)
$C_6H_{15}O_4P$	Triethyl phosphate	−0.688	(84)
$C_6H_{15}P$	Triethylphosphine	−0.762	(84)
$C_7H_4F_3NO_2$	Nitrophenylfluoroform	−0.440	(82)
C_7H_5ClO	Benzoyl chloride (20°)	−0.539	(80)
	(−20°)	−0.561	(80)
$C_7H_5F_3$	Phenylfluoroform	−0.529	(82)
$C_7H_5F_3O$	Trifluorocresol	−0.517	(82)
C_7H_5N	Phenyl cyanide	−0.651	(81)
C_7H_5NO	Phenyl isocyanate	−0.610	(85)
$C_7H_6Cl_2$	Benzal chloride	−0.608	(82)
C_7H_6O	Benzaldehyde	−0.573	(81)
$C_7H_6O_2$	Benzoic acid	−0.556	(45, 46)
C_7H_7Cl	Benzyl chloride (−60°)	−0.661	(80)
	(−30°)	−0.695	(80)
C_7H_7NO	Benzamide	−0.597	(82)
C_7H_7NO	Benzaldoxime	−0.576	(82)
$C_7H_7NO_2$	*o*-Nitrotoluene	−0.532	(82)
C_7H_8	Toluene	−0.729	(81)
C_7H_8O	Benzyl alcohol	−0.705	(81)
C_7H_8O	Anisole	−0.672	(81)
$C_7H_8O_2$	Guaiacol	−0.638	(81)
C_7H_9N	Methylaniline	−0.713	(81)
C_7H_9N	*o*-Toluidine	−0.701	(81)
C_7H_9NO	Anisidine	−0.654	(81)
C_7H_{12}	1-Heptine	−0.807	(82)
C_7H_{12}	2-Heptine	−0.786	(82)
$C_7H_{12}O$	2-Methylcyclohexanone	−0.660	(82)
$C_7H_{12}O$	3-Methylcyclohexanone	−0.667	(82)
$C_7H_{12}O$	4-Methylcyclohexanone	−0.566	(82)
$C_7H_{12}O_2$	Hexahydrobenzoic acid	−0.649	(85)
$C_7H_{12}O_3$	Ethyl 1-methylacetoacetate	−0.590	(81)
$C_7H_{12}O_4$	Diethyl malonate	−0.585	(82)
$C_7H_{14}Cl_2$	Oenanthylidene chloride	−0.589	(81)
$C_7H_{14}O$	Heptaldehyde	−0.714	(81)
$C_7H_{14}O_2$	Ethyl isovalerate	−0.700	(81)
C_8H_5I	1-Iodo-2-phenylacetylene	−0.483	(82)
$C_8H_5NO_2$	Phthalimide	−0.533	(82)
C_8H_6	Phenylacetylene	−0.673	(82)
$C_8H_6O_4$	Phthalic acid	−0.446	(45, 46)
C_8H_7N	Benzyl cyanide	−0.676	(81)
C_8H_8	Styrene	−0.655	(82)
$C_8H_8N_2O_2$	Phthalamide	−0.556	(82)
C_8H_8O	Acetophenone (15°)	−0.597	(80)
	(25°)	−0.621	(80)

TABLE 4.—(*Continued*)

Formula	Name (and temperature)	χ	Lit.
$C_8H_8O_2$	Anisaldehyde	−0.568	(82)
$C_8H_8O_2$	Methyl benzoate	−0.602	(81)
$C_8H_8O_3$	Methyl salicylate	−0.580	(81)
C_8H_9FO	*p*-Fluorophenetole	−0.628	(82)
C_8H_9N	Benzylidenemethylamine	−0.613	(82)
C_8H_{10}	*o*-Xylene (−40°)	−0.728	(80)
	(−10°)	−0.662	(80)
C_8H_{10}	*m*-Xylene	−0.743	(81)
$C_8H_{10}O$	Phenetole	−0.692	(81)
$C_8H_{11}N$	Dimethylaniline	−0.711	(81)
$C_8H_{11}N$	Ethylaniline	−0.709	(81)
$C_8H_{12}Br_2$	2, 5-Dimethyl-2, 5-dibromo-3-hexine	−0.506	(82)
C_8H_{14}	2, 4-Dimethyl-2, 4-hexadiene	−0.714	(85)
$C_8H_{14}O$	Dimethylcyclohexanone	−0.672	(82)
$C_8H_{14}O_2$	Tetramethylketotetrahydrofurfurane	−0.736	(82)
$C_8H_{14}O_2$	2, 5-Dimethyl-3-hexin-2, 5-diol	−0.724	(82)
$C_8H_{14}O_2$	Tetrolic acetal	−0.688	(82)
$C_8H_{14}O_3$	Ethyl 1-ethylacetoacetate	−0.615	(81)
$C_8H_{14}O_4$	Diethyl succinate	−0.604	(82)
$C_8H_{14}O_6$	Diethyl tartrate	−0.550	(82)
C_8H_{16}	Octylene	−0.798	(81)
$C_8H_{16}Br_2$	Octylene bromide	−0.553	(81)
$C_8H_{16}N_2$	Isobutylideneazine	−0.683	(82)
$C_8H_{16}O$	Methyl hexyl ketone	−0.728	(82)
$C_8H_{17}Cl$	Octyl chloride	−0.773	(81)
$C_8H_{17}NO$	Octanonoxime	−0.717	(82)
C_8H_{18}	Octane	−0.872	(81)
$C_8H_{18}O$	Octyl alcohol	−0.806	(81)
$C_8H_{19}N$	Diisobutylamine	−0.848	(81)
C_9H_7N	Quinoline	−0.662	(81)
C_9H_7NO	Phenylpropiolamide	−0.574	(82)
C_9H_8	Indene	−0.730	(82)
C_9H_8O	Cinnamic aldehyde	−0.566	(82)
C_9H_{10}	α-Methylstyrene	−0.678	(82)
C_9H_{10}	Hydrindene	−0.664	(82)
$C_9H_{10}O$	Cinnamyl alcohol	−0.650	(82)
$C_9H_{10}O_2$	Ethyl benzoate	−0.628	(81)
$C_9H_{11}N$	Tetrahydroquinoline	−0.668	(82)
$C_9H_{15}NO$	Hexylpropiolamide	−0.677	(82)
$C_{10}H_7Br$	Bromonaphthalene	−0.598	(81)
$C_{10}H_7NO_2$	α-Nitronaphthalene	−0.564	(82)
$C_{10}H_8$	Naphthalene	−0.717	(82)
$C_{10}H_8O$	Naphthol	−0.673	(82)
$C_{10}H_8O$	Acetylphenylacetylene	−0.731	(82)
$C_{10}H_8O_2$	Methyl phenylpropiolate	−0.573	(82)
$C_{10}H_{10}$	Phenylbutadiene	−0.658	(82)
$C_{10}H_{10}$	Dihydronaphthalene	−0.654	(82)
$C_{10}H_{10}O_2$	Benzoylacetone	−0.586	(82)
$C_{10}H_{10}O_2$	Safrol and isosafrol	−0.601	(81)
$C_{10}H_{12}$	α, ω-Dimethylstyrene	−0.686	(82)
$C_{10}H_{12}O$	Anethole	−0.648	(82)
$C_{10}H_{12}O_2$	Eugenol and isoeugenol	−0.622	(81)
$C_{10}H_{14}$	Cymene	−0.769	(81)
$C_{10}H_{14}O$	Carvone	−0.614	(82)
$C_{10}H_{14}O$	Carvacrol	−0.726	(82)
$C_{10}H_{14}O_3$	Camphoric anhydride	−0.620	(45, 46)
$C_{10}H_{16}O$	Camphor	−0.68	(35)
$C_{10}H_{16}O$	Citral	−0.650	(81)
$C_{10}H_{16}O_2$	Ethyl amylpropiolate	−0.670	(82)
$C_{10}H_{16}O_4$	Camphoric acid	−0.746	(45, 46)
$C_{10}H_{18}O$	Terpineol	−0.725	(85)
$C_{10}H_{18}O$	Eucalyptol	−0.754	(81)
$C_{10}H_{18}O$	Dimethyldiethylketotetrahydrofurfurane	−0.753	(82)
$C_{10}H_{18}O_2$	Diisobutyralacetylene	−0.738	(82)
$C_{10}H_{18}O_3$	Ethyl 1-isobutylacetoacetate	−0.652	(81)
$C_{10}H_{21}N$	Diethylcyclohexylamine	−0.802	(81)
$C_{10}H_{22}$	Decane	−0.876	(81)
$C_{10}H_{22}O$	Isoamyl ether	−0.813	(82)
$C_{10}H_{23}N$	Diisoamylamine	−0.846	(82)
$C_{11}H_9NO_4$	Ethyl nitrophenylpropiolate	−0.502	(82)
$C_{11}H_{10}Br_2O_2$	Ethyl dibromocinnamate	−0.498	(82)
$C_{11}H_{10}O$	Propionylphenylacetylene	−0.601	(82)
$C_{11}H_{10}O_2$	Ethyl phenylpropiolate	−0.598	(82)
$C_{11}H_{12}O_2$	Ethyl cinnamate	−0.610	(82)
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	−0.600	(81)
$C_{11}H_{18}$	Dimethyl-2, 4-nonatriene	−0.990	(85)
$C_{11}H_{18}$	2, 6-Dimethyl-2, 6, 8-nonatriene	−0.724	(82)
$C_{11}H_{18}O_2$	Ethyl hexylpropiolate	−0.684	(82)
$C_{11}H_{18}O_2$	Geraniol formate	−0.658	(81)
$C_{12}H_{10}$	Diphenyl	−0.677	(82)
$C_{12}H_{10}AsCl$	Diphenylchloroarsine	−0.550	(84)
$C_{12}H_{10}N_2$	Azobenzene	−0.612	(82)
$C_{12}H_{10}N_2O$	Hydroxyazobenzene	−0.503	(81)
$C_{12}H_{10}O$	Diphenyl ether	−0.635	(82)
$C_{12}H_{10}O_2S$	Phenylsulfone	−0.591	(84)
$C_{12}H_{11}N$	Diphenylamine	−0.634	(82)
$C_{12}H_{11}NO_2$	Ethyl benzylidenecyanoacetate	−0.578	(82)
$C_{12}H_{11}N_3$	Aminoazobenzene	−0.600	(82)
$C_{12}H_{12}N_4$	Chrysoidine	−0.595	(81)
$C_{12}H_{12}O$	Butyrylphenylacetylene	−0.618	(82)
$C_{12}H_{14}As_2Cl_2N_2O_2.2H_2O$	Salvarsan dihydrochloride	−0.518	(84)
$C_{12}H_{15}N_3O_6$	Triethyl triazinetricarbonate	−0.552	(85)
$C_{12}H_{20}O_2$	Propyl hexylpropiolate	−0.697	(82)
$C_{12}H_{20}O_7$	Triethyl citrate	−0.586	(81)
$C_{12}H_{22}$	Dicyclohexyl	−0.774	(82)
$C_{12}H_{22}O_4$	Diacetal	−0.668	(82)
$C_{12}H_{27}N$	Triisobutylamine	−0.846	(81)
$C_{13}H_8O_2$	Xanthone	−0.551	(82)
$C_{13}H_9N$	Acridine	−0.688	(82)
$C_{13}H_{10}$	Fluorene	−0.665	(82)
$C_{13}H_{10}O$	Benzophenone	−0.594	(82)
$C_{13}H_{11}N$	Benzylideneaniline	−0.554	(82)
$C_{13}H_{12}$	Diphenylmethane	−0.685	(82)
$C_{13}H_{12}N_2O$	*p*-Methoxyazobenzene	−0.560	(82)
$C_{13}H_{13}O_3P$	Methyldiphenoxyphosphine oxide	−0.616	(84)
$C_{13}H_{14}O$	Valerylphenylacetylene	−0.639	(82)
$C_{14}H_8O_2$	Anthraquinone	−0.575	(82)
$C_{14}H_8O_2$	Phenanthraquinone	−0.509	(82)
$C_{14}H_{10}$	Anthracene	−0.726	(82)
$C_{14}H_{10}$	Phenanthrene	−0.718	(82)
$C_{14}H_{10}$	Tolane	−0.667	(82)
$C_{14}H_{10}O_3$	Benzoic anhydride	−0.552	(45, 46)
$C_{14}H_{12}$	1, 1-Diphenylethylene	−0.655	(82)
$C_{14}H_{12}$	Stilbene	−0.666	(82)
$C_{14}H_{12}N_2$	Benzalazine	−0.594	(82)
$C_{14}H_{14}N_2$	Azotoluene	−0.643	(82)
$C_{14}H_{14}N_2O_2$	*p*-Azoanisole	−0.610	(81)
$C_{14}H_{15}N$	Methylbenzylaniline	−0.670	(81)
$C_{14}H_{15}N_3$	Aminoazotoluene	−0.631	(81)
$C_{14}H_{16}O$	Caproylphenylacetylene	−0.651	(82)
$C_{14}H_{22}O_2$	Dicyclohexanolacetylene	−0.682	(82)

TABLE 4.—(*Continued*)

Formula	Name (and temperature)	χ	Lit.
$C_{14}H_{26}O_4$	Diethyl sebacate	−0.685	(82)
$C_{15}H_{13}N$	Cinnamylideneaniline	−0.595	(82)
$C_{15}H_{33}N$	Triisoamylamine	−0.845	(81)
$C_{16}H_{10}$	Diphenyldiacetylene	−0.640	(82)
$C_{16}H_{12}N_2O$	Benzeneazo-β-naphthol	−0.567	(81)
$C_{16}H_{13}N_3$	Methyldiphenyltriazine	−0.627	(85)
$C_{16}H_{18}N_2O_2$	*p*-Azophenetole	−0.635	(81)
$C_{17}H_{14}O$	1-Phenyl-4-benzoyl-1, 3-butadiene	−0.599	(82)
$C_{18}H_{12}$	Chrysene	−0.648	(82)
$C_{18}H_{15}As$	Triphenylarsine	−0.578	(84)
$C_{18}H_{15}AsO$	Diphenylphenoxyarsine	−0.567	(84)
$C_{18}H_{15}AsO$	Triphenylarsine oxide	−0.618	(84)
$C_{18}H_{15}AsO_3$	Triphenoxyarsine	−0.551	(84)
$C_{18}H_{15}Bi$	Triphenylbismuthine	−0.447	(84)
$C_{18}H_{15}BiN_2O_6$	Triphenylbismuthine dinitrate	−0.451	(84)
$C_{18}H_{15}O_3P$	Triphenyl phosphite	−0.592	(84)
$C_{18}H_{15}P$	Triphenylphosphine	−0.636	(84)
$C_{18}H_{15}Sb$	Triphenylstibine	−0.516	(84)
$C_{18}H_{17}AsO_2$	Triphenylarsine dihydroxide	−0.795	(84)
$C_{18}H_{17}O_2Sb$	Triphenylstibine dihydroxide	−0.616	(84)
$C_{18}H_{18}N_3OP$	Trianilinophosphine oxide	−0.624	(84)
$C_{18}H_{34}O_2$	Oleic acid	−0.742	(81)
$C_{19}H_{14}O_3$	Aurin	−0.556	(81)
$C_{19}H_{16}$	Triphenylmethane	−0.674	(82)
$C_{19}H_{16}O$	Triphenyl carbinol	−0.675	(82)

TABLE 5.—SPECIFIC SUSCEPTIBILITY (χ): CRYSTALS

χ_1, χ_2, χ_3 are the three principal values; Ψ = angle between the crystallographic *c* axis and a principal axis of magnetization; room temperature; unit of $\chi = 10^{-6}$ cgsm.

	Substance	χ_1	χ_2	χ_3	Ψ	Lit.
Al_2O_3	Corundum	−0.34	M			(127)
Al_2O_3	Ruby	0.47				(127)
$(AlF)_2SiO_4$*	Topaz	−0.410	−0.420	− 0.420		(112)
$H_2Al_3(BOH)_2Si_4O_{19}$†	Tourmaline	1.12		0.748		(112)
$Be_3Al_2(SiO_3)_6$	Beryl	0.826		0.386		(112)
C‡	Graphite	−2.2		−14.2		(53)
$C_{12}H_{22}O_{11}$	Cane sugar	−0.60	−0.55	− 0.57	− 1° 50′	(34)
CaF_2	Fluorite	−0.285				(55)
$Ca_5Cl(PO_4)_3$	Apatite	−2.64		− 2.64		(112)
$CaCO_3$	Aragonite	−0.392	−0.387	− 0.444		(112)
$CaCO_3$	Calcite	−0.363		− 0.405		(112)
$HCa_2(Al, Fe)_2Si_3O_{13}$*	Epidote	23.8	24.1	23.9		(34)
$CaMgC_2O_6$	Dolomite	0.787		1.20		(112)
(Ca, Mg, Fe)$_2Si_2O_{26}$*	Hornblende	24.0	16.7	18.0	−21° 55′	(34)
$CaMgSiO_6$§	Augite	26.6	12.8	22.7	− 7° 0′	(34)
$CoSO_4.7H_2O$		36.3	32.7	35.0	−39° 40′	(34)
$Co(NH_4)_2(SO_4)_2.6H_2O$		26.1	21.9	25.5	−31° 18′	(57)
$CoCu(SO_4)_2.6H_2O$		28.6	23.1	25.6	−52° 54′	(34)
$CuSiO_3.H_2O$	Dioptasite	8.8	M			(38)
$CuFeS_2$	Chalcopyrite	(*See* $FeCuS_2$)				
FeS_2	Pyrite	0.98				(127)
$FeSO_4.7H_2O$		44.3	41.1	40.2	30° 10′	(34)
$Fe(NH_4)_2(SO_4)_2.6H_2O$		46.2	40.9	40.5	−18° 58′	(34)
$FeCO_3$	Siderite	84.2		142.6		(38)
$FeCuS_2$	Chalcopyrite	0.85	M			(55)
(Fe, Zn, Mn)O.(Fe, Mn)$_2O_3$*	Franklinite	455 to 640				(127)
$K_2Co(SO_4)_2.6H_2O$		30.2	22.4	35.0	−21° 20′	(127)
$KAlSi_3O_8$	Adularia	−0.427	−0.384	− 0.317	−13° 20′	(34)
$MgAl_2O_4$	Spinel	0.62				(127)
NaCl	Rock salt	−0.50				(55)
$NiSO_4.7H_2O$		16.66	16.53	16.63		(57)
$Ni(NH_4)_2(SO_4)_2.6H_2O$		10.2	8.23	9.38	−16° 17′	(34)
PbS	Galena	−0.350				(112)
SiO_2	Quartz	−0.461	−0.466	(*cf.* p. 341.)		(112)
$SrSO_4$	Celestite	−0.342	−0.314	− 0.359		(112)

TABLE 5.—(*Continued*)

	Substance	χ_1	χ_2	χ_3	Ψ	Lit.
TiO_2	Rutile	1.96		2.09		(112)
ZnS	Sphalerite	−0.264				(112)
$ZrSiO_4$	Zircon	−0.170		+ 0.732		(112)

* Composition variable. † H may be replaced by Mg, Fe, or alkalies. ‡ Ceylon. § With addition of (Mg, Fe)(Al, Fe)$_2SiO_5$.

TABLE 6.—SPECIFIC SUSCEPTIBILITY (χ): MISCELLANEOUS SUBSTANCES

Unit of $\chi = 10^{-6}$ cgsm

Substance	χ	Lit.	Substance	χ	Lit.
Air;* 20°C, 1 atm.	24.16*g*	M	Glass, crown†	−0.90	(62, 63)
	24.40*g*	(20)	heavy flint	−1.2	
	23.85*g*	(100)	Linseed oil	−0.74	(35)
	24.40*g*	(122)	Marble; $CaCO_3$	−0.8	(125)
	24.00*g*	(10)	Paraffin	−0.6	(125)
Celluloid	−0.13	(62, 63)	Petroleum	−0.83	(71)
Colza oil	−0.79	(93)	Shellac	−0.30	(71)
Cumene	−0.74	(71)	Terpene	−0.67	(71)
Ebonite	0.6	(125)	Wax, white	−0.6	(125)
Gypsum; $CaSO_4.2H_2O$	−0.86	(62, 63)	Wood	−0.3 to 0.7	(125)

* For κ, *see* Table 1. † Borosilicate.

TABLE 7.—SPECIFIC SUSCEPTIBILITY OF SOLUTIONS: REFERENCES

The solvent is stated at the beginning of each section

Solute	Lit.	Solute	Lit.
H_2O		**H_2O.—(*Continued*)**	
BaI_2*	(62, 63)	$MnCl_2$	(12.1, 92)
$C_2H_4O_2$, Acetic acid	(99)	$MnBr_2$*	(65)
C_3H_6O, Acetone	(99)	MnI_2*	(65)
$CeBr_3$*	(27)	$MnSO_4$	(14)
CoF_2*	(65)	$Mn(NO_3)_2.6H_2O$	(12.1, 92)
$CoCl_2$	(92)	$MnPO_4$*	(117)
$CoBr_2$*	(33)	NiF_2*	(65)
CoI_2*	(65)	$NiCl_2$¶	(119)
$CoSO_4$	(16)	$NiBr_2$*	(65)
$Co(NO_3)_2.6H_2O$	(92)	$NiSO_4$¶	(119)
$CoSO_4.(NH_4)_2SO_4$*	(93)	$Ni(NO_3)_2.6H_2O$¶	(12.1, 119)
$Cr(OH)_2$*	(92)	$PtCl_4$*	(62)
$CrCl_2$*	(117); *cf.* (15)	$YbCl_3$*	(27)
Cr_2Cl_4O*†	(15)	$ZnCl_2$*	(62)
$CrSO_4$*	(15)	**CH_3OH, Methyl alcohol**	
$Cr_2O(SO_4)_2$‡‖	(15)	$CoCl_2$	(92)
$Cr_2(SO_4)_3$*‡§	(14)	$FeCl_3$†	(92)
$Cr(NO_3)_3.9H_2O$	(92)	$MnCl_2$	(92)
$CuCl_2$‖¶	(59)	$Mn(NO_3)_2.6H_2O$	(92)
$CuBr_2$	(59)	**C_2H_5OH, Ethyl alcohol**	
$CuSO_4$‡¶	(59)	$CoCl_2$	(92)
$Cu(NO_3)_2.6H_2O$¶	(59)	$CuCl_2$‖	(59)
$CuC_4H_6O_4.H_2O$**	(92)	$FeCl_3$†	(92)
$ErCl_3$*	(27)	$MnCl_2$	(92)
$FeCl_2$	(92)	$Mn(NO_3)_2.6H_2O$	(92)
$FeCl_3$††	(13)	C_3H_6O, Acetone	(99)
$FeBr_3$*	(65)	**$C_2H_4O_2$, Acetic acid**	
FeI_2*	(65)	$FeCl_3$	(92)
$FeSO_4$¶	(121)	C_6H_6, Benzene	(99)
$Fe_2(SO_4)_3$	(92)	**C_3H_6O, Acetone**	
$Fe(NO_3)_3.6H_2O$‡‡	(13)	$CoCl_2$†	(92)
$FeSO_4.(NH_4)_2SO_4$*	(65)	$FeCl_3$	(92)
KOH*	(62, 63)	$Co(NO_3)_2.6H_2O$	(92)
$K_3Fe(CN)_6$	(45)	**$C_5H_{12}O$, Amyl alcohol**	
$MgSO_4$	(103)	$CoCl_2$	(92)
MnF_2*	(65)		

* *See also* Table 3. † Also acidulated with HCl. ‡ Also in water + H_2SO_4. § Also in water + Na_2SO_4. ‖ Also in water + C_2H_5OH. ¶ Also in water + NH_3. ** Copper acetate. †† Also in aqueous solutions of HCl, of HNO_3, of NaCl. For solutions in methyl, ethyl, isobutyl, allyl or isoamyl alcohol, or in formic acid, acetic acid, ethyl acetate, ethyl ether, or acetone, *see* (92). ‡‡ Also in water + HNO_3.

TABLE 8.—SPECIFIC SUSCEPTIBILITY (χ): ALLOYS AND AMALGAMS

Unit of $\chi = 10^{-7}$ cgsm

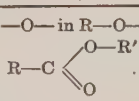
Alloy	Fig.	Lit.	Alloy	Fig.	Lit.
Ag-Sb	2	(28)	Cu-Ni	1	(40, 41, 42)
Al-Sb	2	(53)	Cu-Sb	3	(32)
Al-Zn	2	(28)	Cu-Sn	3	(32)
Bi-Cd	1	(44)	Cu-Zn	3	(32)
Bi-Hg	1	(44)	Pb-Sb	4	(32)
Bi-Pb	3	(32)	Pb-Sn	4	(53)
Bi-Sb	3	(53)	Pb-Tl	4	(32)
Bi-Sn	3	(32)	Sb-Sn	2	(32)
Bi-Te	1	(53)	Sb-Te	2	(32)
Bi-Tl	1	(70)	Sb-Zn	2	(53)
Bi-Zn	1	(32)	Sn-Te	4	(53)
Cd-Pb	4	(44)	Sn-Zn	3	(32)
Cu-Mn	3	(32)			

TABLE 9.—ATOMIC AND ATOMIC GROUP SUSCEPTIBILITIES (χ_a)

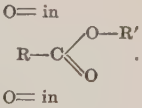
For many compounds, the molecular susceptibility is approximately equal to the sum of χ_a's for the several atomic groups which are contained in the compound; for certain organic groupings a correction (λ_m) must be added to the sum of the χ_a's in order to obtain the value of the molecular susceptibility. Unit of $\chi_a = 10^{-6}$ cgsm per gram atom, or per gram atomic group; of $\lambda_m = 10^{-6}$ cgsm per gram molecule.

Atomic group	χ_a	Atomic group	χ_a	Atomic group	χ_a
Ag^+	−31.0	Sn^{++++}	−30.3	Organic compounds	
Al^{+++}	−13.1	Zn^{++}	−13.5	C	− 6.25
As^{+++}	−20.9	Br^-	−30.60	H	− 3.05
As^{+++++}	−43.0	Cl^-	−20.10	N	− 5.80
Au^{++}	−45.8	F^-	− 6.30	S	−15.60
B^{+++}	− 7.3	I^-	−44.60	O'*	− 4.61
Ba^{++}	−38.2	NO_3^-	−14.2	O''†	− 3.36
Be^{++}	− 8.55	SO^{--}	−13.4	O''‡	+ 1.73
Bi^{+++}	−40.6	$S_2O_3^{--}$	−43.4	λ_m for benzene bond	− 1.50
Bi^{+++++}	−69.8	$S_4O_6^{--}$	−84.7		
Ca^{++}	−15.9	SO_2^-	−17.9		
Cd^{++}	−20	SO_2^{--}	−24.7	λ_m for one ethylene bond	− 5.70
Cs^+	−41.0	SO_3^-	−27.8		
Cu^+	−18.0	SO_3^{--}	−22.3		
Hg^{++}	−33.4	$S_2O_6^{--}$	−56.0	λ_m for two or more ethylene bonds	−11.0
K^+	−18.5	SO_4^-	−31.4		
Li^+	− 4.2	SO_4^{--}	−33.6		
Mg^{++}	−10.1	CO_3^{--}	−22.2		
Na^+	− 9.2	PO^{---}	−22.3		
P^{+++}	−10.2	PO_2^{---}	−18.5		
Rb^+	−27.2	PO_3^{---}	−23.8		
Sb^{+++}	−26.1	PO_3^{----}	−31.3		
Sb^{+++++}	−66.9	PO_4^{----}	−35.4		
Si^{+++}	−20				
Si^{++++}	−12.7				

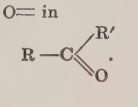
* —O— in R—O—R',



† O= in



‡ O= in



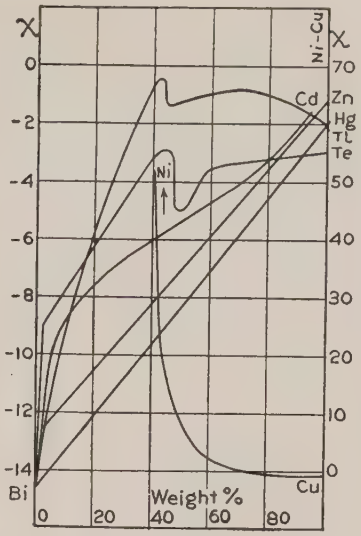


FIG. 1.

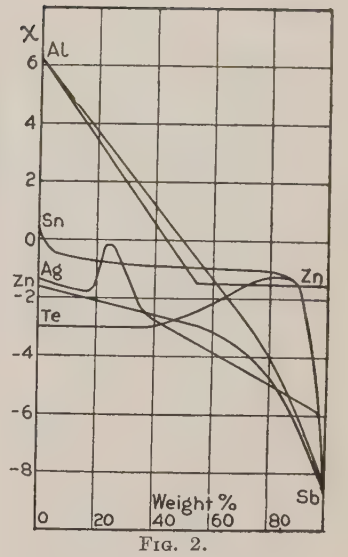


FIG. 2.

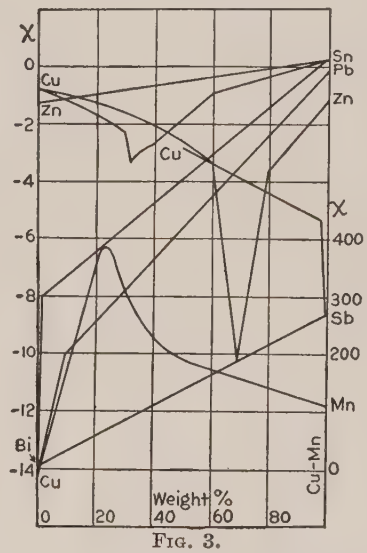


FIG. 3.

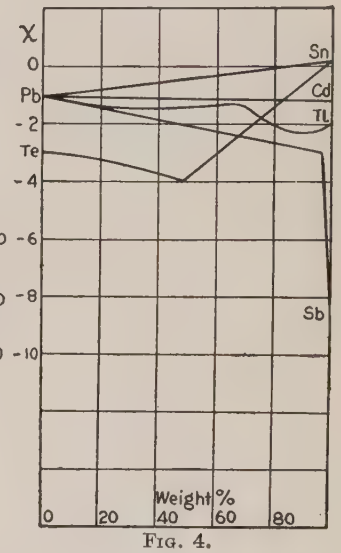


FIG. 4.

FIGS. 1, 2, 3, 4.—Susceptibility (χ) of alloys.
Unit of $\chi = 10^{-7}$ cgsm. Abscissae indicate the weight % of the element named at the right margin.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ångström, *25*, **13**: 1465; 80. (2) Athanasiadis, *8*, **66**: 425; 21. (3) Bauer, Weiss and Piccard, *34*, **167**: 484; 18. (4) Becquerel, *6*, **28**: 283; 50. (5) Becquerel, *6*, **12**: 5; 77. *34*, **92**: 348; 81. (6) Belz, *3*, **44**: 479; 22. (7) Bernini, *63*, **6**: 109; 05. (8) Bernstein, *Diss.*, Halle, 1909. (9) Bouchonnet, *Thesis*, Paris, 1913.

(10) Brant, *2*, **17**: 678; 21. (11) Breit and Onnes, *64P*, **26**: 840; 23. (12) Cabrera, *Soc. franç. de phys.*, Strasbourg sect., June 1, 1923. (12.1) Cabrera and Duperier, *51*, **6**: 121; 25. (13) Cabrera and Moles, *149*, **35**: 425; 13. **36**: 502; 13. **40**: 284; 15. Cabrera, Moles and Guzman, *149*, **37**: 324; 14. (14) Cabrera, Moles and Marquina, *42*, **16**: 11; 18. *10*, **5**: 799; 25. (15) Cabrera and Piña de Rubies, *Rev. Real Acad. Ciencas exac. Fis. Nat. Madrid*, **20**: 385; 23. *10*, **5**: 800; 25. (16) Chatillon, *34*, **176**: 1608; 23. (17) Chéneveau, *51*, **9**; 163; 10. Chéneveau and Jolley, *3*, **20**: 357; 10. (18) Cherbuliez, *Diss.*, Zürich, 1917. *10*, **5**: 799; 25. (19) Clifford, *2*, **26**: 424; 08.

(20) Curie, *34*, **115**: 1292; 92. **116**: 136; 93. *51*, **4**: 197; 95. (21) de Haas and Drapier, *8*, **42**: 673; 13. (22) Piccard and Devaud, *149*, **2**: 455; 20, (23) Dewar, *121*, **29**: 169; 92. (24) Drapier, *42*, **7**: 385; 09. (25) Du Bois. *8*, **35**: 137; 88. (26) Du Bois and Honda, *64P*, **12**: 596; 10. (27) Du Bois and Liebknecht, *8*, **1**: 189; 00. (28) Dupuy, *34*, **158**: 793; 14. (29) Eaton, *8*, **15**: 225; 82.

(30) Efimov, *51*, **7**: 494; 88. (31) Balta Elias, *Trab. lab. inv., fis.*, **44**: 110; 18. *10*, **5**: 799; 25. (32) Endo, *159*, **14**: 479; 25. (33) Falckenberg, *96*, **5**: 70, 201; 21. (34) Finke, *8*, **31**: 149; 10. (35) Faraday, *8*, **88**: 557; 53.

(36) Feytis, *34*, **152**: 708; 11. **153**: 668; 11. **156**: 886; 13. (37) Fleming and Dewar, *5*, **60**: 283; 97. **63**: 311; 98. (38) Foëx, *16*, **16**: 174; 21. (39) Frivold, *8*, **57**: 471; 18.
(40) Gans and Fonseca, *8*, **61**: 742; 20. (41) Garrison, *1*, **47**: 622; 25. (42) Gebhard, *Diss.*, Marburg, 1909. (43) Glaser, *8*, **75**: 459; 24. (44) Gnesotto and Binghinotto, *24*, **69**: 1343; 10. **72**: 1515; 13. **74**: 25; 14. **75**: 333; 15. (45) Gray and Birse, *4*, **105**: 2707; 14. (46) Hadfield, Chéneveau and Géneau, *5*, **94**: 65; 17. *34*, **166**: 390; 18. (47) Hector, *2*, **24**: 218; 24. (48) Henning, *8*, **50**: 485; 93. (49) Henrichsen, *8*, **34**: 180; 88. **45**: 38; 92.
(50) Heydweiller, *8*, **12**: 608; 03. *88*, **15**: 1120; 13. (51) Honda, *8*, **32**: 1027; 10. *159*, **1**: 1; 12. (52) Honda and Ishiwara, *159*, **4**: 215; 15. **6**: 9; 17. (53) Honda and Soné, *159*, **2**: 1; 13. (54) Ihde, *Diss.*, Marburg, 1912. *8*, **41**: 829; 13. (55) Ishiwara, *159*, **3**: 303; 14. **5**: 53; 16. **9**: 233; 20. Takagi and Ishiwara, *159*, **3**: 127; 14. (56) Isnardi and Gans, *8*, **61**: 585; 20. (57) Jackson, *62*, **224**: 1; 23. (58) Jackson and Onnes, *34*, **177**: 154; 23. *5*, **104**: 671; 23. (59) Jacobson, *Thesis*, Zürich, 1916.
(60) Jäger and Meyer, *75*, **106**: 594, 623; 97. **107**: 5; 98. *8*, **67**: 427, 707; 99. (61) Jolley, *121*, **65**: 1021; 10. *3*, **20**: 357; 10. (62) König, *8*, **31**: 273; 87. (63) Koenigsberger, *8*, **66**: 698; 98. **6**: 506; 01. (64) Laws, *3*, **8**: 49; 04. (65) Liebknecht and Wills, *8*, **1**: 178; 00. (66) Lombardi, *Mem. real accad. Torino*, **47**: 1; 97. (67) Lutteroth, *8*, **66**: 1081; 98. (68) Maass and Hatcher, *1*, **44**: 2472; 22. (69) Marke, *61*, **1916**: 395.
(70) Mendenhall and Lent, *2*, **32**: 406; 11. (71) Meslin, *6*, **7**: 145; 06. (72) Meyer, quoted by Wedekind, *25*, **54**: 253; 21. (73) Meyer, *8*, **68**: 325; 99. **69**: 236; 99. **1**: 664; 00. *63*, **26**: 51; 25. (74) Morgan and Lammert, *1*, **46**: 881; 24. (75) Mosler, *8*, **6**: 84; 01. (76) Muthmann, quoted by Wedekind, *25*, **54**: 253; 21. (77) Onnes and Oosterhuis, *64P*, **15**: 322; 12. *168*, **No. 129b**; 12. *64P*, **16**: 917; 14. *168*, **No. 139e**; 14. (78) Onnes and Perrier, *64P*, **12**: 799; 10. *168*, **No. 116**; 10. *64P*, **14**: 115; 11. *168*, **No. 122a**; 11. *64P*, **14**: 674; 12. *168*, **No. 124a**; 12. *168*, **Suppl. No. 44a**; 21. Perrier and Onnes, *64P*, **16**: 894; 14. *168*, **No. 139c**; 14. *64P*, **16**: 901; 14. *168*, **No. 139d**; 14. (79) Owen, *8*, **37**: 657; 12.
(80) Oxley, *62*, **214**: 109; 14. (81) Pascal, *34*, **147**: 56, 242, 742; 08. **148**: 413; 09. **150**: 1167; 10. *27*, **7**: 17, 45; 10. *6*, **19**: 5; 10. (82) Pascal, *34*, **152**: 862, 1010; 11. *27*, **9**: 6, 79, 134, 177, 336; 11. **10**: 809, 868; 11. **11**: 159, 201, 636; 12. *6*, **25**: 289; 12. (83) Pascal, *34*, **156**: 323; 13. **158**: 37; 14. *6*, **29**: 218; 13. (84) Pascal, *34*, **173**: 144, 712; 21. **174**: 457, 1698; 22. **175**: 1063; 22. (85) Pascal, *34*, **176**: 1887; 23. **177**: 765; 23. **180**: 1596; 25. (86) Piaggesi, *63*, **4**: 347; 03. (87) Piccard and Devaud, *149*, **2**: 455; 20. Bauer, Weiss and Piccard, *34*, **167**: 484; 18. Weiss and Piccard, *34*, **155**: 1234; 12. (88) Piccard and Bonazzi, *149*, **39**: 449; 15. (89) Piccard and Devaud, *149*, **2**: 410; 20.
(90) Pidgeon, *2*, **13**: 209; 19. (91) Plessner, *8*, **39**: 336; 90. (92) Quartaroli, *36*, **46 I**: 371; 16. **48 I**: 79; 18. (93) Quincke, *8*, **24**: 347; 85. **34**: 401; 88, (94) Roop, *63*, **12**: 48; 11. *2*, **7**: 529; 16. (95) Safranek, *74*, **21**: 87; 24. (96) Scarpa, *59*, **10**: 155; 05. (97) Seckelson, *8*, **67**: 37; 99. (98) Sève, *6*, **27**: 425; 12. (99) Smith and Smith, *1*, **40**: 1218; 18.
(100) Soné, *159*, **8**: 115; 19. **11**: 139; 22. *3*, **39**: 305; 20. (101) Stearns, *2*, **16**: 1; 03. (102) Stenger, *8*, **35**: 331; 88. (103) Studley, *2*, **24**: 22; 07. (104) Tänzler, *8*, **24**: 931; 07. (105) Theodorides, *149*, **3**: 137; 21. *Thesis*, Zürich, 1921. (106) Toepler and Henning, *8*, **34**: 790; 88. (107) Townsend, *5*, **60**: 186; 96. (108) Trümpler, *Thesis*, Zürich, 1917. *10*, **5**: 798; 25. (109) Urbain, *34*, **152**: 141; 11.
(110) Urbain and Jantsch, *34*, **147**: 1286; 08. (111) Veil, *34*, **176**: 101; 23. (112) Voigt and Kinoshita, *8*, **24**: 492; 07. (113) von Ettinghausen, *75*, **96**: 777; 87. *8*, **17**: 272; 82. (114) Wedekind, *92*, **37**: 87; 24. (115) Wedekind and Hausknecht, *25*, **46**: 3763; 13. **54**: 253; 21. (116) Wedekind and Horst, *25*, **45**: 262; 12. **48**: 105; 15. (117) Weber, *8*, **19**: 1056; 06. **36**: 624; 11. **62**: 666; 20. (118) Weiss and Piccard, *34*, **155**: 1234; 12. Bauer, Weiss and Piccard, *34*, **167**: 484; 18. (119) Weiss and Bruins, *64P*, **18**: 246; 15.
(120) Weiss and Foëx, *149*, **31**: 5; 11. *51*, **1**: 274; 11. (121) Weiss and Frankamp, *64P*, **18**: 254; 15. (122) Weiss and Piccard, *34*, **155**: 1234; 12. (123) Wiedemann, *8*, **126**: 1: 65. **135**: 177; 68. (124) Williams, *2*, **12**: 158; 18. **14**: 348; 19. (125) Wills, *3*, **45**: 432; 98. *2*, **20**: 188; 05. (126) Wills and Hector, *2*, **23**: 209; 24. (127) Wilson, *5*, **98**: 274; 21. **103**: 185; 23. (128) Wirth, quoted by Wedekind, *25*, **54**: 253; 21. (129) Wistband, *Diss.*, Upsala, 1916. (129.1) Woltjer, *64V*, **34**: 494; 25.
(130) Woltjer and Onnes, *64P*, **26**: 626; 23. *168*, **No. 167c**; 23. (131) Wylach, *Diss.*, Münster, 1915.

FERROMAGNETISM

PIERRE WEISS AND G. FOËX

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Those materials to which most frequent reference will probably be made are listed in Table 1 in the order of their composition, and *"key" numbers* are there assigned them. In other places, they are, in general, identified by these key numbers only. Data for other alloys and compounds will be found in their appropriate places in the several tables. For a general exposition of the subject of ferromagnetism, *see* (77).

Les matières auxquelles il sera probablement fait appel le plus fréquemment sont disposées dans la Table 1 dans l'ordre de leur composition, et on a assigné à chacune d'elles un *nombre "clé."* Aux autres places, ces matières sont en général identifiées seulement par leurs nombres-clés. Les données relatives aux autres alliages et composés seront trouvées à leurs places appropriées dans les nombreuses tables. Pour une exposition générale du sujet du ferromagnétisme, *voir* (77).

Dasjenige Material, welches wahrscheinlich am häufigsten in Frage kommen wird, ist in der Tafel 1 in der Reihenfolge seiner Zusammensetzung angeordnet, und *Schlüsselzahlen* sind ihm angefügt. An anderer Stelle sind die Stoffe im allgemeinen nur durch die Schlüsselzahlen gekennzeichnet. Die Daten für andere Legierungen und Verbindungen sind an den zuständigen Stellen der verschiedenen Tafeln zu finden. Eine allgemeine Darlegung über den Ferromagnetismus, *v.* (77).

Le sostanze più interessanti sono elencate nella Tabella 1 secondo l'ordine della loro composizione e ad esse sono attribuiti *numeri chiave* con cui sono in genere designate. Dati per altre leghe e composti sono riportati nelle diverse tabelle. Per una esposizione generale sull' argomento del ferromagnetismo, *v.* (77).

Symbols	Symboles	Symbole	Simboli
Subscript Symboles	**Symboles des Indices**	**Symbole für Indexzeichen**	**Simboli di Sottoscritti**
a Annealed, if appended to designation of specimen or to *t*.	*a* Recuit, si annexé à la désignation d'un échantillon ou à *t*.	*a* Angelassen, wenn die Bezeichnung der Probe oder dem *t* angefügt ist.	*a* Ricotto, se aggiunto alla designazione del campione o a *t*.
a Alternating field, if appended to *W*.	*a* Champ alternatif, si annexé à *W*.	*a* Wechselstromfeld, wenn dem *W* angefügt.	*a* Campo alternante, se aggiunto a *W*.
c As cast, if appended to designation of specimen.	*c* Coulé, si annexé à la désignation d'un échantillon.	*c* Wie gegossen, wenn der Bezeichnung der Probe angefügt.	*c* Come ottenuto di getto, se aggiunto alla designazione del campione.
c Coercive, if appended to *H*.	*c* Coercitif, si annexé à *H*.	*c* Koerzitiv, wenn *H* angefügt.	*c* Coercitivo, se aggiunto ad *H*.

d	Drawn.	*d*	Étiré.	*d*	Gezogen.	*d*	Rinvenuto.
l	Value for large grains, *see* p. 379.	*l*	Valeur pour de gros grains, *voir* p. 379.	*l*	Werte für grobe Stücke, *siehe* S. 379.	*l*	Valore per grani grossi, *v.* p. 379.
max.	Maximum.	max.	Maximum.	max.	Maximum.	max.	Massimo.
n	Normal.	*n*	Normal.	*n*	Normal.	*n*	Normale.
q	Quenched.	*q*	Trempé.	*q*	Abgeschreckt.	*q*	Temprato.
r	Residual.	*r*	Résiduel.	*r*	Restlich.	*r*	Residuo.
red.	Reduced, corrected for presence of impurities.	red.	Réduit, corrigé à cause de la présence d'impuretés.	red.	Reduziert, korrigiert wegen der Anwesenheit von Verunreinigungen.	red.	Ridotti, corretto per la presenza di impurezze.
s	Spontaneous.	*s*	Spontané.	*s*	Selbsttätig	*s*	Spontaneo.
t	Value at temperature *t*.	*t*	Valeur à la température, *t*.	*t*	Wert bei der Temperatur, *t*.	*t*	Valore alla temperatura, *t*.
δ	Differential or reversible.	δ	Différentiel ou reversible.	δ	Differentiell oder reversibel.	δ	Differenziale o reversibile.
τ	Turning or rotating.	τ	Tournant ou animé d'un mouvement de rotation.	τ	Drehend oder rotierend.	τ	Girante o rotante.
0	Initial value, $H = 0$.	0	Valeur initiale, $H = 0$.	0	Anfangswert, $H = 0$.	0	Valore iniziale, $H = 0$.
∞	Saturation value, H very great.	∞	Valeur de saturation, H très grand.	∞	Sättigungswert, H sehr gross.	∞	Valore di saturazione, H molto grande.

Symbols for Quantities		Symboles pour Quantités		Symbole für Grössen		Simboli per Quantità	
a, *a'*	Coefficients of magnetic hardness (*see* definition).	*a*, *a'*	Coëfficients de dureté magnétique (*voir* définition).	*a*, *a'*	Koeffizient der magnetischen Härte (*siehe* Definition).	*a*, *a'*	Coefficienti di durezza magnetica (*vedi* definizione).
B	Magnetic induction.	*B*	Induction magnétique.	*B*	Magnetische Induktion.	*B*	Induzione magnetica.
B_μ	Value of B corresponding to μ_m (max.).	B_μ	Valeur de B correspondant à μ_m (max.).	B_μ	Werte von B, die μ_m (max.) entsprechen.	B_μ	Valore di B corrispondente a μ_m (massimo).
d	Density; occasionally = diameter.	*d*	Densité; occasionnellement = diamètre.	*d*	Dichte, zuweilen Durchmesser.	*d*	Densità, qualche volta = diametro.
e	Hysteresis exponent.	*e*	Exposant d'hystérésis.	*e*	Hysteresis-Exponent.	*e*	Esponente di isteresi.
H	Magnetic field intensity.	*H*	Intensité du champ magnétique.	*H*	Intensität des magnetischen Feldes.	*H*	Intensità del campo magnetico.
I	Intensity of magnetization.	*I*	Intensité de magnétisation.	*I*	Intensität der Magnetisierung.	*I*	Intensità della magnetizzazione.
l	Length.	*l*	Longueur.	*l*	Länge.	*l*	Lunghezza.
Key	Key number as given in Table 1.	Key	Mêmes nombres-clés que ceux donnés dans la Table 1.	Key	Schlüsselzahl, wie in der Tabelle 1 vorhanden.	Key	Numero chiave riportato nella Tabella 1.
p	Percentage by weight of constituent under consideration.	*p*	Pourcentage poids du constituant considéré.	*p*	Gewichtsprozente des betrachteten Konstituenten.	*p*	Percentuale in peso del componente che si considera.
s	Side of section of square rod.	*s*	Côté d'une section d'une tige de section carrée.	*s*	Seitenlänge des Querschnittes eines vierkantigen Stabes.	*s*	Lato di sezione di una sbarra quadrata.
t	Temperature, °C.	*t*	Température, °C.	*t*	Temperatur, °C.	*t*	Temperatura, °C.
t_R	Room temperature.	t_R	Température ambiante.	t_R	Zimmertemperatur	t_R	Temperatura ambiente.
W	Hysteresis loss per cm^3 per cycle.	*W*	Perte par hystérésis par cm^3 par cycle.	*W*	Hysteresisverlust pro cm^3 pro Cykl.	*W*	Perdita di isteresi per cm^3 e per ciclo.
α	Temperature coefficient of electrical conductivity; $(\rho_t - \rho_0) = \alpha\rho_0 t$.	α	Coëfficient de température de conductibilité électrique; $(\rho_t - \rho_0) = \alpha\rho_0 t$.	α	Temperaturkoeffizient der elektrischen Leitfähigkeit; $(\rho_t - \rho_0) = \alpha\rho_0 t$.	α	Coefficiente di temperatura della conducibilità elettrica; $(\rho_t - \rho_0) = \alpha\rho_0 t$.
β	Temperature coefficient of I; $I_t - I_0 = \beta I_0 t$.	β	Coëfficient de température de I; $I_t - I_0 = \beta I_0 t$.	β	Temperaturkoeffizient von I; $I_t - I_0 = \beta I_0 t$.	β	Coefficiente di temperatura di I; $I_t - I_0 = \beta I_0 t$.
η	Hysteresis (Steinmetz) coefficient.	η	Coëfficient d'hystérésis (Steinmetz).	η	Hysteresiskoeffizient (Steinmetz).	η	Coefficiente di isteresi (Steinmetz).
Θ	Curie point, °C.	Θ	Point de Curie, °C	Θ	Curie-Punkt, °C.	Θ	Punto di Curie, °C.
κ	Susceptibility.	κ	Susceptibilité.	κ	Suszeptibilität.	κ	Suscettività.
λ	Wave-length *in vacuo*.	λ	Longueur d'onde dans le vide.	λ	Wellenlänge im Vakuum.	λ	Lunghezza d'onda nel vuoto.
μ	Permeability.	μ	Perméabilité.	μ	Permeabilität.	μ	Permeabilità.

ρ	Electrical volume resistivity.	ρ	Résistance électrique.	ρ	Elektrischer Widerstand.	ρ	Resistività elettrica.
σ	Specific magnetization; $\sigma = I/d$.	σ	Magnétisation spécifique; $\sigma = I/d$.	σ	Spezifische Magnetisierung; $\sigma = I/d$.	σ	Magnetizzazione specifica; $\sigma = I/d$.
σ_∞	Saturation value of σ at absolute zero.	σ_∞	Valeur de saturation de σ au zéro absolu.	σ_∞	Sättigungswert von σ beim absoluten Nullpunkt.	σ_∞	Valore di saturazione di σ allo zero assoluto.
σ'_∞	Saturation value of σ at temperature of observation.	σ'_∞	Valeur de saturation de σ à la température de l'observation.	σ'_∞	Sättigungswert von σ bei der Beobachtungstemperatur.	σ'_∞	Valore di saturazione di σ alla temperatura di osservazione.
τ_d	Time specimen was kept at drawing temperature.	τ_d	Temps durant lequel l'échantillon a été maintenu à la température d'étirage.	τ_d	Zeitdauer während welcher die Probe bei der Temperatur gehalten wurde, bei welcher sie gezogen ist.	τ_d	Durata di permanenza del campione alla temperatura di rinvenimento.
φ	Azimuth of H.	φ	Azimuth de H.	φ	H-Azimut.	φ	Azimut di H.
χ	Specific susceptibility; $\chi = \kappa/d$.	χ	Susceptibilité spécifique; $\chi = \kappa/d$.	χ	Spezifische Suszeptibilität; $\chi = \kappa/d$.	χ	Suscettività specifica; $\chi = \kappa/d$.

Units and Conversion Factors

In the Ferromagnetic section of the Tables all data, excepting those for resistivity (ρ), are expressed in cgsm units and centigrade temperatures, unless the contrary is explicity stated; for ρ the unit is 1 microhm-cm.

B 1 cgsm = 1 maxwell cm^{-2} = 1 line cm^{-2} = 6.452 line $in.^{-2}$.

d 1 cgsm = 1 g cm^{-3} = 0.03613 lb. $in.^{-3}$ = 62.43 lb. $ft.^{-3}$.

e A pure number.

H 1 cgsm = 1 gauss = 1 gilbert cm^{-1} = 0.7957 ampere turn per cm = 2.021 ampere turn per in.

I 1 cgsm = 1 cgsm magnetic moment cm^{-3} = 4π* maxwell cm^{-2} = 4π* line cm^{-2} = 6.452 × 4π* line $in.^{-2}$ = 16.387 cgsm magnetic moment $in.^{-3}$.

W 1 cgsm = 1 erg cm^{-3} per cycle = 10^{-7} watt cm^{-3} per (cycle sec^{-1}) = 16.39 × 10^{-7} watt $in.^{-3}$ per cycle-sec^{-1} = d_M × 10^{-7} watt g^{-1} per cycle-sec^{-1} = 16.39 d_E × 10^{-7} watt $lb.^{-1}$ per cycle-sec^{-1}. (d_M, d_E are densities expressed in g cm^{-3}, lb. $in.^{-3}$, respectively).

η 1 cgsm = 1 erg cm^{-3} per cycle per (maxwell $cm^{-2})^e$ = 1 000^e erg cm^{-3} per cycle per (kiloline $cm^{-2})^e$ = 1 000^e × 10^{-7} watt cm^{-3} per cycle-sec^{-1} per (kiloline $cm^{-2})^e$ = (155.0)^e × 10^7 watt cm^{-3} per cycle-sec^{-1} per (kiloline $in.^{-2})^e$ = 16.387 × (155.0)^e × 10^7 watt $in.^{-3}$ per cycle-sec^{-1} per (kiloline $in.^{-2})^e$ = 16.387 × (1 000)^e × 10^{-7} watt $in.^{-3}$ per cycle-sec^{-1} per (kiloline $cm^{-2})^e$. (For e = 1.6, 1 $000^{1.6}$ = 63 096, (155.0)$^{1.6}$ = 3 195.4, 16.387 × (155.0)$^{1.6}$ = 52 364, 16.387 × (1 000)$^{1.6}$ = 1.0338 × 10^6).

κ 1 cgsm = 4π* maxwell cm^{-2} per gauss = 1.2566 × 4π* maxwell cm^{-2} per ampere-turn-cm^{-1} = 0.4947 × 4π* maxwell cm^{-2} per ampere-turn-$in.^{-1}$ = 6.452 × 4π* line $in.^{-2}$ per gauss = 8.107 × 4π* line $in.^{-2}$ per ampere-turn-cm^{-1} = 3.192 × 4π* line $in.^{-2}$ per ampere-turn-$in.^{-1}$.

μ 1 cgsm = 1 maxwell cm^{-2} per gauss = 1.2566 maxwell cm^{-2} per ampere-turn-cm^{-1} = 0.4947 maxwell cm^{-2} per ampere-turn-$in.^{-1}$ = 6.452 line $in.^{-2}$ per gauss = 8.107 line $in.^{-2}$ per ampere-turn-cm^{-1}.

ρ 1 microhm-cm = 1 000 cgsm = 10^{-6} ohm-cm = 0.3937 microhm-in.

σ 1 cgsm = 1 cgsm magnetic moment g^{-1} = 4π* maxwell cm g^{-1} = 4π* line cm g^{-1} = 178.6 × 4π* line in. $lb.^{-1}$ = 453.6 cgsm magnetic moment $lb.^{-1}$.

χ 1 cgsm = 4π* maxwell cm g^{-1} per gauss = 178.6 × 4π* line in. $lb.^{-1}$ per gauss = 453.6 cgsm magnetic moment $lb.^{-1}$ per gauss.

*4π = 12.566; 0.4947 × 4π = 6.217; 1.2566 × 4π = 15.791; 3.192 × 4π = 40.11; 6.452 × 4π = 81.07; 8.107 × 4π = 101.88; 178.6 × 4π = 2244.4.

Numerical Relations

$\mu_n = B_n/H = 1 + 4\pi\kappa_n$; $\mu = B/H = 1 + 4\pi\kappa$; $B = H + 4\pi I$; $B_r = 4\pi I_r$; $I = \kappa H$; $I_n = \kappa_n H$; $\sigma = I/d = \chi H$; $\sigma_n = I_n/d$; $W = \eta B^e_{max.}$ If H is great, $1/\kappa = a + bH$; $\sigma = \sigma_\infty\ (1 - a'H)$ if $\sigma \gtrsim 0.99\sigma_\infty$, $a' = a\sigma_\infty$.

Definitions

Anneal.—When a specimen of material has been kept at a high temperature (t_a) for such a length of time that it has come to equilibrium, and is then slowly cooled, it is said to have been annealed from t_a; t_a = annealing temperature.

Anhysteretic.—Those data obtained when the specimen, while in a constant field (H), is subjected to an alternating field which is progressively reduced from a value $> H$ to 0. The same result can be obtained by subjecting the specimen to repeated mechanical shocks. To a first approximation, such data are single valued functions of H.

Coercive Force.—When the field, in which a specimen is placed, is reduced from a finite value ($H_{max.}$) to 0, I is reduced to a certain finite value I_r, which is called the *residual* magnetization after the application of the force $H_{max.}$ The residual induction, or *retentivity*, is $B_r = 4\pi I_r$. In order to reduce B to 0, a reverse field of intensity H_c must be applied; H_c is the *coercive force*, or *coercive field*, corresponding to $H_{max.}$ When the value of $H_{max.}$ (or of $B_{max.}$) is not stated, it is understood to exceed that corresponding to saturation.

Curie Point.—Generally, the rising temperature at which the material ceases to be ferromagnetic, or the falling temperature at which it becomes ferromagnetic. These two temperatures do not coincide in all cases, and, unless the contrary is stated, it is to be understood that the observations were made with increasing temperature. More exactly, the Curie point is the temperature, Θ, that occurs in the equation of Weiss, $\chi(t - \Theta)$ = constant, which is satisfied by ferromagnetic materials if t is greater than, but not too nearly equal to Θ. In this region χ is independent of the field, and χ^{-1} is linear in t (the linear law of Weiss). In a small transition region around Θ, the graph of (χ^{-1}, t) is curved; consequently this Θ is, in general, a little higher than that at which ferromagnetism disappears. At the Curie point, the graph showing the variation of the specific heat with the temperature has a discontinuity and the reversible evolution of heat accompanying a change in H (the magnetocaloric phenomenon of Weiss) has a sharp maximum (77, 84, 85).

Drawn.—If an unannealed specimen is heated to a moderate temperature t_d for a time τ_d and then cooled slowly it is said to have been *drawn* to the temperature t_d for the time τ_d.

Differential Susceptibility.—If the intensity of the field is varied repeatedly over the range H to H-dH, the value of I ultimately varies between the fixed value I and I-dI, then $dI/dH = \kappa_\delta$ is the *differential*, or *reversible*, susceptibility. The differential permeability is $\mu_\delta = 1 + 4\pi\kappa_\delta$. To a first approximation, these quantities are single valued functions of I.

Hardness.—If H is great, $4\pi H/(B - H) = 1/\kappa = a + bH$, where a and b are constants [37]; and approximately $\sigma = \sigma_\infty\left(1 - \frac{a'}{H}\right)$, where $a' = aI_\infty$ [73]. The quantities a and a' measure the magnetic *hardness* of the material. They vary with the impurities and with the heat treatment of the specimen.

Hysteresis.—When the field varies systematically and cyclically between $+H_{max.}$ and $-H_{max.}$, the (B, H) curve, after a few cycles, is closed. This closed curve is called the *hysteresis loop*. During each cycle, there is dissipated within the specimen, and in addition to the dissipation by the Foucault currents, an amount of energy (W) which is proportional to the volume of the specimen (if the field is uniform) and to the area of the loop. This is the *hysteretic loss*. It depends not only upon the specimen and the value of $H_{max.}$, but also upon the manner in which the cycle is traced—whether H varies by a series of finite steps, or is proportional to $\sin\tau$, or is constant in amount but varies in direction, etc. When H varies as $\sin\tau$ (τ = time), W is called the *alternating hysteretic loss* and, when desirable, is denoted by W_a; unless the contrary is stated, W will be understood to denote W_a. When the specimen is a body of revolution, and the field, constant in intensity, rotates uniformly about the axis of revolution—or the field is fixed and the body rotates—W is called the *turning* or *rotating hysteretic loss*, denoted by W_τ. As $H_{max.}$ is increased, W_τ passes through a maximum and tends to 0 in very intense fields. All hysteretic losses vary greatly with the heat treatment of the specimen. In general, $W = \eta B^e_{max.}$; η = *hysteresis*, or *Steinmetz*, coefficient; e = *hysteresis exponent;* for most irons and steels, $e = 1.6$; this value is to be assumed unless another is stated.

Initial.—The initial permeability (μ_0) is value of μ when $H = 0$.

Normal.—The permeability ($\mu = B/H$) of a specimen depends upon its magnetic history, but the permeability ($\mu_n = B_{max.}/H_{max.}$) at the tip of a repeatedly traced hysteresis loop is definite; it is called the *normal permeability* corresponding to $H = H_{max.}$ The corresponding susceptibility (κ_n), induction (B_n), and magnetization (I_n) are likewise said to be *normal*. The locus of the positive tips of the hysteresis loops corresponding to various values of $H_{max.}$ is called the *normal* (B, H) curve, or the curve of first magnetization.

Quenched.—When a specimen while at a high temperature (t_q) is quickly cooled by being plunged into a large volume of liquid (water, oil, mercury, etc.) it is said to have been quenched at temperature t_q.

Reduced.—Data which have been corrected for the effects produced by the impurities in the specimen are said to be "reduced," denoted by "red." (Constituents characteristic of the type of material under consideration are not impurities; *e.g.*, in carbon irons, C is not an impurity, but in electrolytic iron, C is an impurity.)

Residual.—*See* Coercive force.

Rotating Hysteresis.—*See* Hysteresis.

Saturation.—The saturation values (σ_∞, I_∞) of σ and I are their values at absolute zero and for $H = \infty$. Values (σ'_∞, I'_∞) for $H = \infty$, but at temperature of observation (not absolute zero) are also called saturation values.

Specific Magnetization.—Magnetic moment per unit of mass; $\sigma = I/d$.

Spontaneous.—The magnetizations of the several structural elements composing a specimen are in general inclined to one another. Hence the observed, or apparent, magnetization of the specimen is less than the true magnetization of its elements. The latter may be determined by thermomagnetic measurements [75]. Representing the latter as a function of H, H great, and extrapolating to $H = 0$, a value called the *spontaneous* magnetization (I_s, σ_s) of the material is obtained.

TABLE 1.—KEY NUMBER AND COMPOSITION OF EACH OF VARIOUS SPECIMENS OF IRON, COBALT, NICKEL, THEIR ALLOYS, AND ALLOYS CONTAINING MANGANESE AND COPPER

Those alloys which occur in only a single table and are of such a nature that there is no reason for comparing their compositions with those of others are not included in this list. When materials from distinctly different sources have the same composition, they are distinguished in the property tables by roman numerals appended to the key number. Amounts expressed in % by weight.

Key number	Material	% C	% Si	% Mn	% S	% P	Tables
	Carbon irons and pure Fe						
1	Electrolytic Fe; fused *in vacuo* (3 mm Hg)						4
1.1	Electrolytic Fe; fused *in vacuo;* Heraeus; extremely pure						6
2	Electrolytic Fe; fused *in vacuo;* total impurities = 0.02%						22
3	Electrolytic Fe; fused in H; Merck						6, 22
4	Electrolytic Fe; fused in N; Merck						4, 6, 22
5	Pure iron. Data obtained from commercial materials; correction applied for effect of impurities						4
6	Electrolytic Fe; fused *in vacuo*	0.0015			0.014		6
7	Electrolytic Fe; fused *in vacuo*	0.0017			0.014		6
8	Electrolytic Fe; fused *in vacuo*	0.0018			0.014		6
9	Electrolytic Fe	0.004	0.007		0.006	0.011	3, 22
10	Electrolytic Fe; fused *in vacuo*	0.006	0.01				6
11	Iron, 0.006% Cu	0.009	0.005		0.009		22
12	Iron, 0.006% Cu	0.009	0.006		0.009		22
13	Electrolytic Fe; fused in H, 0.072% H	0.012	0.003	0	0.001	0.004	6
14	Electrolytic Fe + C	0.018	0.004	Tr.	0.011		9
15	Electrolytic Fe	0.024	0.004	0.008	0.001	0.008	6
16	Swedish charcoal iron	0.027	0.006	0.030	0.002	0.099	3, 4, 9, 11
17	Swedish charcoal iron						5
18	Mild steel; dynamo steel	0.044	0.004	0.400	0.027	0.044	3, 4, 9, 11
19	Swedish iron	0.046	0.006	0.12			5

TABLE 1.—(*Continued*)

Key number	Material	% C	% Si	% Mn	% S	% P	Tables
	Carbon irons and pure Fe.—(*Continued*)						
20	Taylor iron	<0.05					4
21	American ingot iron	<0.05					4
22	Norway iron	<0.05					4
23	Best refined iron	<0.05					4
24	Soft iron						2, 5, 11
25	Bessemer steel	0.05					4
26	Firminy	0.06					12, 14
27	Iron, 0.03% Cu	0.08	0.01	0.06	0.01	0.01	22
28	Mild steel; dynamo	0.085	0.028	0.380	0.024	0.029	4, 9, 11
29	Kohlswa iron	0.09	0.04	0.06	0.009	0.024	4
30	Bessemer steel	0.1					4
31	Electrolytic Fe + C	0.14	0.01	0.002	0.020		9
32	Bessemer steel	0.15					4
33	Firminy	0.20					12, 14
34	Hard steel	0.23	0.04	0.18	(?)	0.08	9, 11
35	Electrolytic Fe + C	0.23	0.006	0.004	0.020		9
36	Electrolytic Fe + C	0.32	0.007	Tr.	0.009		9, 10
37	Electrolytic Fe + C	0.39	0.004	Tr.	0.009		10
38	Mild steel, no As	0.44			0	0	5
39	Firminy	0.49					12, 14, 15
40	Electrolytic Fe + C	0.52	0.003	Tr.	0.011		9
41	Hard steel	0.69	0.16	0.13	0.08	0.02	9, 11
42	Firminy	0.84					12, 13, 14
43	Eutectoid steel,* 0.05% Cr	0.85	0.23	0.23	0.014	0.016	9, 11
44	Electrolytic Fe + C	0.88	0.018	0.006	0.011		9, 10
45	Electrolytic Fe + C	0.96	0.017	0.004	0.009		10
46	Unieux	0.96					12, 14
47	Hard steel	0.99	0.24	0.28	0.01	0.01	9, 11
48	High carbon steel	0.99	0.10	0.40	0.07	0.04	3
49	Drill rod	1.10					4
50	Firminy	1.21					12, 14
51	Electrolytic Fe + C	1.28	0.025	Tr.	0.008		9
52	Electrolytic Fe + C	1.32	0.006	Tr.	0.011		9
53	Unieux	1.40					14
54	Unieux	1.41					14
55	Electrolytic Fe + C	1.55	0.004	Tr.	0.003		9
56	Hard steel	1.57	0.23	0.37	0.01	0.01	9, 11
57	Electrolytic Fe + C	1.60	0.005	Tr.	0.005		9
58	Unieux	1.61					14
59	Hard steel	1.78	0.10	0.17	0.08	0.02	9, 11
	Silicon steels						
60	Silicon steel	0.25	1.03	0.09	0.04	0.02	17
61	Silicon steel	0.21	2.40	0.08	0.04	0.01	17
62	Stalloy		3				3
63	Silicon steel	0.06	3.71	0.31	0.01	0.01	17
64	Silicon steel†	0.07	4.09	0.10	0.01		17
65	Ferrosilicon		4.4				2
66	Dynamo sheets		4 to 5				3
67	Silicon steel	0.29	4.45	0.12	0.03	0.02	17
	Series of alloys; Si = 0.001% to 4.92%; *see*						17
68	Cast iron	3.109	3.270	0.560	0.061	1.050	4, 9, 11
	Manganese steels						
70	Manganese steel	0.46		0.7			12
71	Manganese steel	0.10	0.03	2.76			17
72	Manganese steel	0.09	0.04	4.20			17
73	Manganese steel	0.13	0.05	5.74			17
74	Manganese steel	0.20	0.09	7.81			17
75	Manganese steel	0.22	0.11	10.30			17
76	Manganese steel	0.20	0.13	12.34			17

* The magnetic properties of commercial tool steel lie between those of the annealed and of the quenched eutectoid.

† More recent than **60, 61, 63, 67.**

TABLE 1.—(*Continued*)

Key number	Material	% Al	% C	% Si	% Mn	% S	% P	Tables
	Aluminium steels							
77	Aluminium steel	2.17	0.13	0.06	0.10			17
78	Aluminium steel	5.66	0.15	0.14	0.10			17
79	Aluminium steel	10.52	0.10	0.09	0.10			17
	Boron steels							17
		% W / % Cr / % Co						
	Cobalt steels							
79-*a*	Electrolytic Fe and pure Co (Merck), fused in H							17
80	Cobalt steel	10	1.37		4.7			13
81	Cobalt steel	5.4 / 10	1.22		3.9			13
82	Cobalt steel	5.1 / 20	1.11		3.5			13
83	Cobalt steel	22	1.16		4.4			13
84	"K. S." magnet steel; range	5 / 1.5 / 30 / 0.4 — 9 / 3 / 40 / 0.8						12, 14, 16
85	Cobalt steel	33	1.15		4.4			13
86	Fe_2Co	34.55						4, 17
87	Cobalt steel	35	0.83		4.8			13
88	Cobalt steel	35	1.12		4.7			13
89	Cobalt steel	35	1.24		4.0			13
90	Cobalt steel	4.8 / 36	1.11		3.5			13
	Chrome steels							17
	Copper iron alloys							17
		Mo						
	Molybdenum steel							
91	Châtillon and Commentry "A"	3.5	0.51					13, 16
92	Châtillon and Commentry "B"	3.4	1.25					13, 14, 16
93	Châtillon and Commentry "B"	4.0	1.24					13, 15, 16
94	Châtillon and Commentry "C"	3.9	1.72					13, 14, 16
		% Al / % Ni						
	Nickel iron alloys; nickel steels							
95	Electrolytic Fe, pure Ni							17
96	Electrolytic*	0.005 / 0.5	0.014	Tr.	Tr.	0.003	Tr.	17
97	Electrolytic* + Si	0.005 / 0.5	0.014	0.2	Tr.	0.003	Tr.	17
98	Electrolytic* + Si	0.005 / 1.0	0.014	0.2	Tr.	0.003	Tr.	17
99	Electrolytic*	0.005 / 1.96	0.014	0.001	Tr.	0.003	Tr.	17
100	Electrolytic* + Si	0.005 / 1.96	0.014	0.2	Tr.	0.003	Tr.	17
101	Nickel steel, "Ni 2"	3	0.7					12
102	Electrolytic*	0.005 / 3.85	0.015	0.001	Tr.	0.003	Tr.	17
103	Electrolytic* + Si	0.005 / 3.85	0.015	0.2	Tr.	0.003	Tr.	17
104	Electrolytic*	0.005 / 5.68	0.015	0.002	Tr.	0.003	Tr.	17
105	Electrolytic* + Si	0.005 / 7.00	0.015	0.2	Tr.	0.003	Tr.	17
106	Electrolytic*	0.005 / 7.33	0.015	0.003	Tr.	0.003	Tr.	17
107	Electrolytic* + Si + Mn	0.005 / 8.0	0.016	0.2	0.1	0.003		17
108	Electrolytic* + Si	0.005 / 9.52	0.016	0.2	Tr.	0.003	Tr.	17
109	Electrolytic*	0.004 / 9.61	0.016	0.004	Tr.	0.003	Tr.	17
110	Electrolytic* + 0.2% Ti	0.004 / 9.9	0.016	0.004	Tr.	0.003	Tr.	17
111	Electrolytic* + Mn + Si	0.004 / 10.0	0.016	0.2	0.1	0.003	Tr.	17
112	Electrolytic*	0.004 / 11.10	0.016	0.004	Tr.	0.003	Tr.	17
113	Electrolytic* + Si	0.004 / 15.0	0.017	0.2	Tr.	0.003	Tr.	17
114	Electrolytic* + 0.2% Ti	0.004 / 15.0	0.017	0.006	Tr.	0.003	Tr.	17
115	Electrolytic*	0.004 / 15.87	0.017	0.006	Tr.	0.003	Tr.	17
116	Electrolytic* + 0.2% Ti	0.004 / 20.0	0.017	0.008	Tr.	0.004	Tr.	17
117	Electrolytic*	0.004 / 21.03	0.017	0.008	Tr.	0.004	Tr.	17
118	Electrolytic* + Al	0.2 / 23.8	0.018	0.009	Tr.	0.004	Tr.	17
119	Electrolytic* + 0.2% Ti	0.004 / 25.0	0.018	0.010	Tr.	0.004	Tr.	17
120	Electrolytic* + Al	0.2 / 25.1	0.018	0.010	Tr.	0.004	Tr.	17
121	Electrolytic* + Al	0.2 / 29.8	0.019	0.012	Tr.	0.004	Tr.	17
122	Electrolytic* + Si	0.003 / 30.0	0.019	0.2	Tr.	0.004	Tr.	17
123	Electrolytic*	0.003 / 38.92	0.020	0.016	Tr.	0.004	Tr	17

* Both the Fe and the Ni are electrolytic; the Fe contains traces of Cu.

TABLE 1.—(*Continued*)

Key number	Material	% Al	% Ni	% C	% Si	% Mn	% S	% P	Tables
	Nickel iron alloys; nickel steels.—(*Continued*)								
124	Electrolytic* + Mn	0.003	50	0.022	0.020	0.5	0.005	Tr.	17
125	Electrolytic*	0.002	54.08	0.023	0.022	Tr.	0.005	0.001	17
126	Electrolytic* + Mn	0.002	54.9	0.023	0.022	0.5	0.005	0.001	17
127	Electrolytic*	0.002	57.99	0.024	0.024	Tr.	0.005	0.001	17
128	Electrolytic*	0.002	66.96	0.025	0.027	Tr.	0.005	0.001	17
129	Electrolytic*	0.001	75.80	0.026	0.030	Tr.	0.005	0.001	17
130	Permalloy, 0.37% Co; 0.10% Cu		78.3	0.04	0.003	0.22	0.035	Tr.	17
131	Permalloy		78.5						3
132	Electrolytic* + Mn	Tr.	89.9	0.029	0.036	0.5	0.006	0.001	17
133	Electrolytic* + Mn	Tr.	93.3	0.029	0.037	0.5	0.006	0.001	17
134	Electrolytic* + Mn	0	99.2	0.030	0.040	0.5	0.006	0.001	17
		% Cr	% V						
	Vanadium iron alloys								
135	Vanadium steel	0	3.5	0.60	Tr.	0.22			17
			% W						
	Tungsten steels								
136	Assailly "V 2"		2.7	0.76					12, 13
137	Assailly "V 3"		2.7	1.10					13
138	Châtillon and Commentry "b"		2.7	1.02					13
139	Assailly "V"		2.9	0.55					13
140	Boehler† "special, extra hard"		2.9	1.10					13, 14
141	Châtillon and Commentry "a"		3.2	0.77					13
142	Châtillon and Commentry "c"		3.5	1.53					13
143	Allevard		5.5	0.59					12, 13, 14, 15, 16
144	Boehler† "Boreas"		7.7	1.96					13, 14, 15
	Cobalt and nickel								
145	Cobalt; fused *in vacuo;* 99% pure								4, 22
146	Cobalt								4, 18
146.1	Nickel; electrolytic, fused *in vacuo;* from Heraeus; 99.9% pure								19
147	Nickel; fused in H; extremely pure, from Merck								19
148	Nickel; fused in N; extremely pure, from Merck								4
149	Nickel, Ni = 99.15%; Mn = 0.7%								19
150	Nickel, Ni = 98.08%, Co = 1.31%; Fe = 0.68%; insoluble = 0.11%								3
151	Nickel, contains 1.5% Co								19
152	Nickel; from $Ni(CO)_4$								22
153	Nickel; purity not stated								19
	Nickel alloys: Alloys with Fe, *see* Table 17 (Ni); others, *see* Table 20								
				% Pb	% Al	% Sn	% Mn	% Cu	
	Manganese alloys containing Cu								
154	Heusler alloy				7.2		13.9	78.9	22
155	Heusler alloy (malleable)				10.15		14.25	75.6	21
156	Heusler alloy				10.15		14.2	75.65	21
157	Heusler alloy				13.2		6.0	80.8	22
158	Heusler alloy				14.0		19.3	66.6	22
159	Heusler alloy (not malleable)			0.1	15.0		23.5	61.5	21
160	Heusler alloy				16.3		26.5	57.2	22
161	Heusler alloy				25		11.6	63.4	22
162	Tin-manganese-copper alloy					14.1	25.1	60.2	21
163	Tin-manganese-copper alloy					16.1	24.5	58.7	21
164	Tin-manganese-copper alloy					18.0	23.9	57.6	21
165	Tin-manganese-copper alloy					29.8	20.4	49.2	21
166	Tin-manganese-copper alloy					38.0	18.1	43.4	21
167	Tin-manganese-copper alloy					48.1	15.0	36.4	21

* Both the Fe and the Ni are electrolytic; the Fe contains traces of Cu.

† Styria.

Illustrative Data

TABLE 2.—ILLUSTRATIVE OF NORMAL, ANHYSTERETIC, AND DIFFERENTIAL MAGNETIZATION

See also Tables 5(**19**), 19(**153***I*)

24*I*, Soft iron; (*cf.* Table 11(**24***I*)

H (65)	Normal		Anhysteretic		Differential* (20)	
	$4\pi I_n$	μ_n	$4\pi I$	μ	I	μ_δ
0.04			5 570	150 000	0	91.2
0.14	170	1 200			165	89.7
0.22			8 680	40 000	308	85.0
0.23	690	3 020			491	77.5
0.54	5 160	9 560			593	74.6
0.62			11 280	18 100	799	62.1
0.73	6 940	9 500			1 010	45.2
3.67	13 730	3 740			1 100	37.4
5.51			14 800	2 690	1 230	22.6
7.79	14 930	1 920			1 370	13.8
20.7	15 970	770				
35.5			16 620	470		
37.4	16 660	446				
58.3			17 310	296		
71.2	17 560	248				
106.8	18 240	172	18 240	172		
164.5	19 100	177	19 100	117		

* Does not refer to same material as the 4 preceding columns.

65 Ferrosilicon; 4.4% Si; anhysteretic (65)

H	$4\pi I$	μ	H	$4\pi I$	μ
0.01	850	85 000	2.49	9 870	3 960
0.02	1 400	70 000	8.41	12 750	1 520
0.05	1 970	40 000	38.6	14 670	380
0.15	3 290	21 000	60.0	15 350	257
0.58	5 200	9 000	179.9	17 640	99
1.39	7 820	5 600			

EFFECT OF TIME

Irrespective of the action of Foucault currents, the magnetization of a material, in general, lags behind changes in H. For annealed soft iron, the lag is very marked; for other materials it is small. This effect is frequently ascribed to a magnetic viscosity; on account of it, the hysteresis cycle may vary markedly with the rate at which H is varied. At very high frequencies, μ_n (max.) decreases rapidly as the frequency is increased, and at frequencies above 3×10^{10} per sec (wave-length (λ) *in vacuo* = 1 cm) μ_n (max.) = 1, even for Fe (*see* Figs. 1 to 5).

TABLE 3.—MAGNETIZATION IN VERY WEAK FIELDS

When H is sufficiently small, $\kappa = a + bH$ and $W = \frac{1}{3}bH^3$ (57). The values of a and of b vary markedly with thermal treatment of the specimen. They vary in a very complicated fashion with the temperature, pass through an acute maximum near the Curie point, and become zero at that point. As the temperature changes progressively from −188°C to Curie point, they satisfy the relation $bc = a^n$; the values of c and of n depend upon the substance and its past thermal treatment. For composition, *see* Table 1.

TABLE 3.—(*Continued*)

9 Electrolytic iron (C = 0.004%) heated repeatedly to 800°C, alternating with cooling to 700°C, annealed from 800°C. At temperatures between 90 and 150°C, and at $t > 330$°C, it ages very rapidly. At 130°C and $H = 0.0957$, κ decreases to ½ its initial value in 10 hr and to ¼ in 24 hr; $n = 1.66$, c varies from 11 to 14 (58).

16 Swedish charcoal iron; C = 0.027%, $\mathbf{16}_c$ = as cast, unannealed; $\mathbf{16}_a$ = annealed.

18 Dynamo steel; C = 0.044%, $\mathbf{18}_{a1}$ = once annealed; $\mathbf{18}_{a2}$ = twice annealed.

48 High carbon steel; C = 0.99%; $\mathbf{48}_a$ = annealed; $\mathbf{48}_q$ = quenched.

62 Stalloy; Si = 3%.

66 Silicon steel, dynamo sheets; Si = 4 to 5%.

131*I* Permalloy; Ni = 78.5%.

150 Nickel (Co = 1.31%) in a condition, obtained by annealing, which was stable during observations between room temperature and Curie point; $n = 4$, $c = 1225$ (55). After annealing again, $n = 4.09$, $c = 2165$ (t increasing); $n = 4.07$, $c = 2145$ (t decreasing) (82), *see* Fig. 7; $a = 7.188[(I_\infty - I)/I]^{1/4}$ (55).

Near Curie point (376°C) there is thermal irreversibility (82).

μ_n, permeability in weak fields: typical materials

H	**9**	$\mathbf{16}_c$	$\mathbf{16}_a$	$\mathbf{18}_{a1}$	$\mathbf{18}_{a2}$	$\mathbf{48}_a$	$\mathbf{48}_q$	**62**	**66**	**131***I*
0	750	214	470	490	320	72.8	43.2	320	528	10 500
0.01		222	513	522	351	72.8	43.2		554	13 800
0.03		242	600	586	433	72.8	43.3		611	36 300
0.05		266	680	650	540	72.9	43.4		668	
0.1		322	890	786	872	73.0	43.6		804	
0.15		374	1 070	912	1 390	73.1	43.8		930	
0.2		430	1 225	1 040	3 030	73.3	44.0		1 035	
0.3						73.5	44.2			
0.4						73.8	44.5			
Lit.	(58)	(26)		(26)		(26)		(46)	(26)	(38)

κ, Susceptibility: typical materials ($\kappa = a + bH$)

Material	$4\pi a$	$4\pi b$	H (limits)*	Lit.
$\mathbf{9}_c$ Electrolytic iron (unannealed)	102	8.5		(58)
$\mathbf{9}_a$ Electrolytic iron	628	1358		(58)
$\mathbf{9}_a$ Electrolytic iron	754			(58)
9 Electrolytic iron aged at 130°C	201	176		(58)
Iron sheets	569	1106	0.07 to 0.75	(30)
Cast steel	235	168	0.07 to 0.9	(30)
Iron containing C	209	234	0.01 to 0.7	(30)
Iron wire, hard	74	22.0	0.1 to 1.1	(30)
Iron wire, not annealed	80	64		(57)
Cast iron	40	3.0	0.1 to 4.0	(30)
Tungsten steel, annealed	112	3.1	0.1 to 3.1	(30)
Tungsten steel, quenched	28	0.4	0.1 to 3.5	(30)
Magnetite,† artificial	16.5	0.475	0.3 to 1.1	(58)

* Limits of H within which $\kappa = a + bH$.

† Pure Fe_3O_4 prepared by roasting Fe_2O_3; $n = 2.4$, $c = 52.3$; *see also* p. 410.

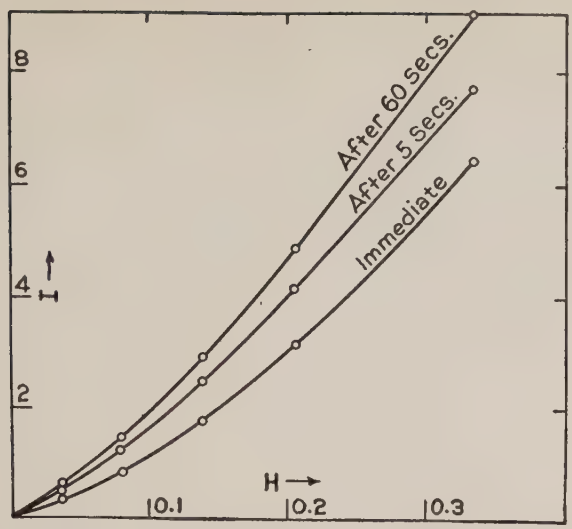

FIG. 1.—Time lag of magnetization (I) in weak fields [16]. Annealed, wrought iron wire.

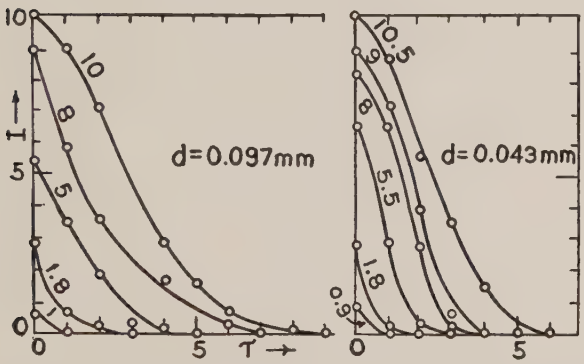

FIG. 3.—Time rate of decrease of magnetization [89]. Hard steel wire, diameter = d, H_c *ca.* 6. Values of I at various intervals after H has been reduced instantaneously to 0; initial value of H is marked on curve. Unit of $\tau = 10^{-6}$ sec.

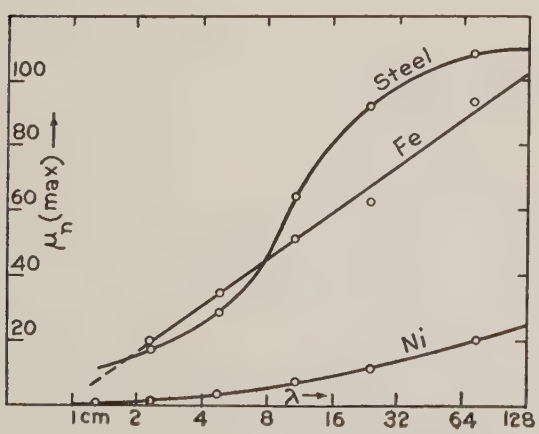

FIG. 5.—Variation of maximum permeability with frequency of H [2]. (*See also* Fig. 4.)

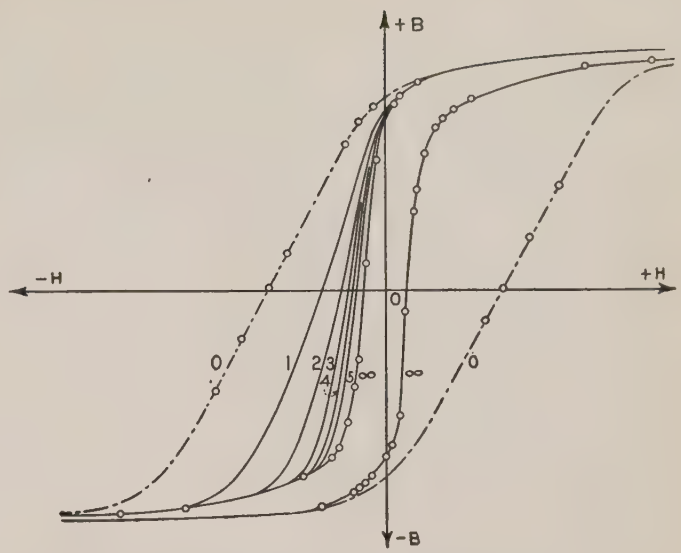

FIG. 2.—Variation of hysteresis cycle with rate of change of H [42]. Annealed electrolytic iron. The curves are loci of isochronal values of B, obtained thus: H is instantaneously reduced from $+H_{max.}$ to a certain chosen fixed value, and B is measured at once and then after intervals of $\frac{1}{3}$, $\frac{2}{3}$, . . . sec. These ordinates and the chosen common abscissa define points on the curves 0, 1, 2, . . . ; the corresponding ascending curves are given for the intervals 0 and ∞ only. For a very slow cycle, $H_c = 0.39$; for a very rapid one, $H_c = 2.18$.

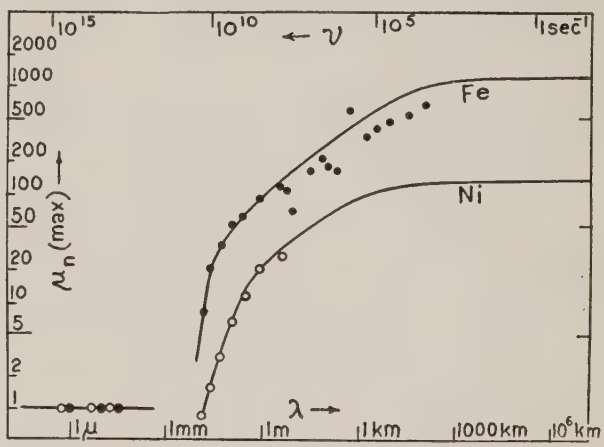

FIG. 4.—Variation of maximum permeability with frequency (ν) of H. Various authors, *see* [2]. λ = wave-length *in vacuo*. *See also* Fig. 5.

TABLE 3.—(*Continued*)

150; κ, Susceptibility: nickel [55]

t	a	b	t	a	b	t	a
18.5	3.68	0.154	244	5.68	0.861	+ 18	3.13
26.0	3.78	0.158	275	6.20	1.214	−183.1	0.954
47.0	3.90	0.187	293	6.60	1.511	−196.6	0.879
65.0	4.02	0.209	309	6.97	1.905	+ 18	3.06
80.0	4.11	0.236	322	7.44	2.402	−252.6	0.779
100.0	4.26	0.272	333	7.90	3.09	+ 18	3.06
124.5	4.44	0.323	344	8.73	4.54	[50]	
150.0	4.65	0.393	353	9.91	8.04		
179.0	4.90	0.502	357	11.65	14.55		
204.0	5.14	0.594	358	6.68	19.18		
220.0	5.37	0.708	376*	0	0		

* Irreversibilities in this region [82].

Table 4.—Magnetization in Intense Fields

The data here given are mainly illustrative; additional data of the same kind will be found in the tables giving data for specific materials. The relative accuracy of data of the same series and obtained by the same method is greater than the absolute accuracy.

For large values of H, $1/\kappa = a + bH$ (37) and approximately $\sigma = \sigma_\infty(1 - a'/H)$ (73); $a' = aI_\infty$. Co is an exception; it is magnetically very hard, and in intense fields the law of variation of σ with H varies with the specimen; for a relatively soft Co, $3600 < H < 6300$ gauss, $\sigma = 162\left[1 - \frac{1.11(10)^6}{H^2}\right]$ at 17°C (73). Both a and a' vary considerably with heat treatment and impurities. For composition, *see* Table 1.

1 Electrolytic iron, cast at pressure = 3 mm Hg.

4 Electrolytic iron, Merck, cast in N.

5 Pure iron (corrected for effects of impurities); $d = 7.876$ g/cm³.

16 Swedish charcoal iron.

29 Kohlswa iron; C = 0.09%; **29′** = corrected for effect of C, Si, Mn.

68 Cast iron; **68**$_c$ = as cast; **68**$_a$ = annealed.

86 Fe_2Co; **86**I_1 = cast under pressure of 1 mm Hg, forged; for **86**I_2 the pressure = 0.5 mm Hg. **86***II*, method of preparation is not stated. $I_\infty(Fe_2Co) = 1.14I_\infty(Fe)$.

145 Cobalt, cast under pressure of 1 mm mercury.

146 Cobalt, relatively soft.

148 Nickel, Merck, cast in N.

Key	Material	H		t	I_∞	σ_∞	a	Lit.
1	Electrolytic iron			t_R	1798			(88)
4	Electrolytic iron	760	6500	17.3		216.1	7.9	(73)
5	Pure iron			t_R	1720			(22)
16$_a$	Swedish charcoal iron			t_R	1685			(22)
18$_a$	Dynamo steel			t_R	1705			(22)
28$_a$	Dynamo steel			t_R	1691			(22)
29	Kohlswa iron	1500	6500	19		216.5	7.9	(73)
29′	Kohlswa iron		<6414	19		218.3*		(73)
68$_a$	Cast iron			t_R	1333			(23)
68$_c$	Cast iron			t_R	1307			(23)
86I_1	Fe_2CoI			t_R	2050			(88)
86I_2	Fe_2CoII			t_R	2056			(88)
86*II*	Fe_2CoIII			t_R	1884			(23)
145	Cobalt, 99 %			t_R	1504			(88)
146	Cobalt, soft	3600	6300	17		162†	†	(73)
148	Nickel, pure	676	8380	18		54.5	9.7	(73)
	Magnetite‡			19		90.7	39	(73)
	Magnetite, pure Fe_3O_4			19		93.3		(39)

* Corrected for effect of C, Mn, Si.

† *See* text at head of table.

‡ Contains a little Fe_2O_3.

Other commercial irons and steels (52)

Key	Material	H	I*	%C	Remarks†	**21***II*	
						H	I_n
20*I*	Taylor	2490	1645	<0.05	slag >	40.5	1343
20*II*	Taylor	2685	1654	<0.05	slag >	68.8	1398
21*I*	American ingot	2760	1708	<0.05	ferrite	129.9	1476
21*I′*	American ingot	4395	1711	<0.05	ferrite	229.8	1570
21*II*	American ingot	2780	1725	<0.05	ferrite	271	1597
21*II′*	American ingot	4545	1735	<0.05	ferrite	399	1660
22*I*	Norway	2885	1685	<0.05	slag <	457	1684
22*II*	Norway	2770	1661		slag <	871	1715
22*III*	Norway	2770	1727		slag <	1126	1717
22*IV*	Norway	4360	1742		slag <	1569	1719
23*I*	Best refined	2740	1620	<0.05	slag >	2288	1724
23*II*	Best refined	2825	1589	<0.05	slag >	2747	1727
23*III*	Best refined	2690	1611	<0.05	slag >	4543	1735
25	Bessemer	2880	1671	0.05			
30*I*	Bessemer	2695	1663	0.1 *ca.*			
30*II*	Bessemer	2675	1687	0.1 *ca.*			
30*III*	Bessemer	2825	1666	0.1 *ca.*			
30*IV*	Bessemer	2370	1685	0.1 *ca.*			
32	Bessemer	2730	1727	0.15			
49	Drill rod	2790	1533	1.10			

* Essentially = I'_∞. † After "slag," > denotes much; <, little.

Table 5.—Effect of Temperature: Swedish Iron and Mild Steel

For Curie and other transformation points, *see* Table 22; for pure Fe, Co, Ni, *see* Tables 6, 18, 19; for Cu-Mn-Sn alloys, *see* Table 21; for magnet steels, *see* Table 16; for magnetite crystal, *see* Table 23; for composition, *see* Table 1.

Key	Material: description and notes
17*I*	Swedish iron; annealed 4 hr at 1000 to 1100°C; studied at 27°C, then plunged in liquid air and studied (34).
17*II*	Swedish iron; annealed in H. After giving it a known residual magnetization (I_r) it was placed in field $H = 0$ (terrestrial and demagnetizing fields were compensated) and heated to successive temperatures at which the resulting values of I ($\equiv I'_r$) were measured. Curves of (I'_r, t) are reversible and relatively homologous (Fig. 8); law of variation of σ'_r with t is same as that of σ_∞ with t (Fig. 9) (49).
19	Swedish iron (C = 0.046%); annealed 20 min at 800° *ca.*; thermal irreversibilities were not prominent (44).
24*II*	Soft iron; annealed at 800°C; relation between H_c and t is very definite and shows no thermal irreversibility (19).
38	Mild steel (C = 0.44%); wire; heated to 1200°C for a day, surrounded by porphyrized iron; during measurements it was sealed in Pt tube (14).

17*I* (34)				**19*** (44)				
27.5°C		−186°C		Normal			Anhysteretic	
H	I_n	H	I_n	t_0	I_n	μ_n	I	μ
1.77	81	2.23	77	15	10	1 380	435	60 000
3.55	243	3.39	247	100			470	64 800
4.10	582	4.55	453	200			523	72 200
7.40	890	5.00	578	300	16	2 200	502	69 200
16.3	1 138	15.4	1 085	400			465	64 100
30.3	1 251	44.7	1 302	500	21.7	3 000	416	57 300
53.4	1 330	135.0	1 464	550			396	54 600
103.7	1 419	221.8	1 543	600	43.5	6 000	424	58 500
234.6	1 545	283.9	1 587	680			500	69 000
349	1 609	385	1 636	700	108	14 900	473	65 200
473	1 647	478	1 665	750	166	22 900		
554	1 621	543	1 681					

* H = 0.091 gauss.

17*II* (49)		**17***II* (48)				**24***II* (19)			
t	σ'_r/σ_r	t	W_r	W	W/W_r	t	H_c	t	H_c
t_R	1.00	18	12 800	17 200	1.35	−185	2.44	467	1.49
286	0.935	100	11 400	15 700	1.37	− 79	2.36	493	1.44
405	0.854	200	9 980	13 800	1.38	+ 21	2.28	553	1.22
517	0.743	300	8 240	11 600	1.41	220	2.00	607	1.09
605	0.655	400	6 020	8 560	1.42	303	1.84	643	1.01
653	0.596	500	3 580	4 900	1.36	360	1.70	656	0.84
763	0.000	600	2 540	2 760	1.08	385	1.53	670	0.71
		700	873	896	1.02	419	1.48	721	0.74
		760	0	0		$H_{max.}$ = 950 gauss.			

38	σ, Specific magnetization (14); *see* Fig. 10				
H \ t	20.0°C	275.0°C	477.0°C	601.0°C	688.0°C
10		117(?)	117(?)	114(?)	89(?)
15	123(?)	126(?)	129(?)	129	100
25	136.0	138	140.5	137.0	108.6
50	153.7	151.8	155.0	147.8	114.7
75	164.3	162.0	166.2	152.0	117.9
100	171.8	171.1	173.0	154.9	119.9
150	183.7	184.3	180 3	158.8	121.8
300	201.3	200.3	186.8	162.9	124.7

Continued on p. 378

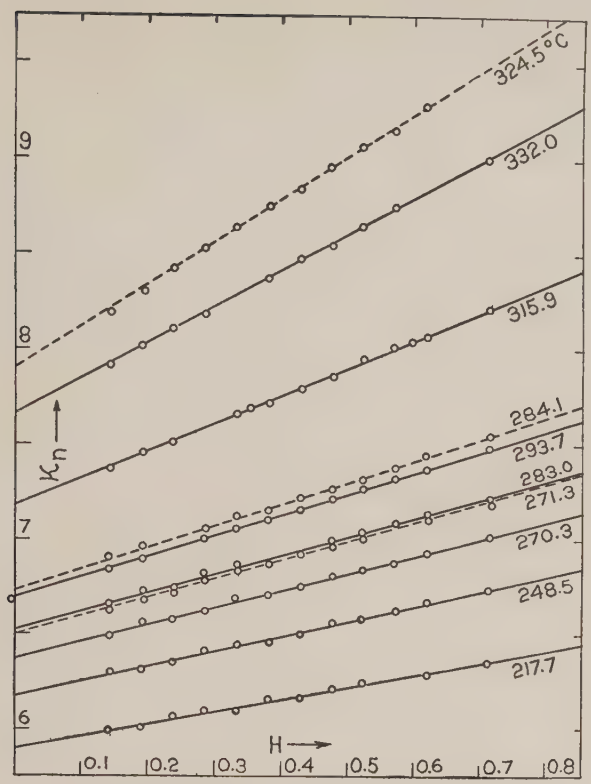

FIG. 7.—Susceptibility (κ_n) of nickel (150) in weak fields (82)

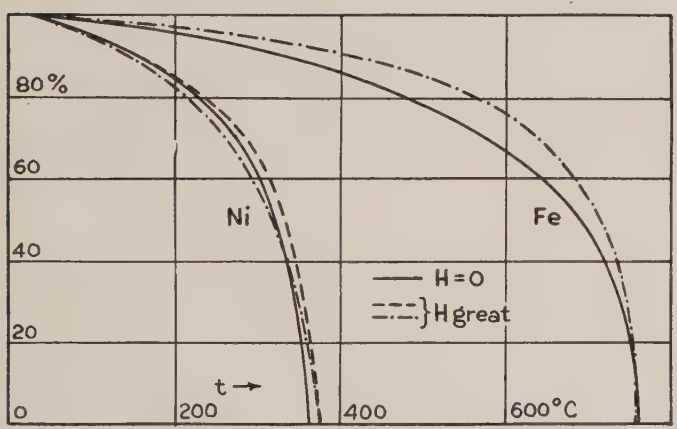

FIG. 9.—Temperature variation of residual magnetization (σ'_r) and of magnetization at saturation ($\sigma_{\infty,t}$). Various authors, *v.* (49). Ordinates are σ'_r/σ_r, if $H = 0$; $\sigma_{\infty,\,t}/\sigma_{\infty,20}$ if H is great. At room temperature and $H = 0$, residual magnetization is σ_r; keeping $H = 0$, the specimen is heated to temperature t and the magnetization becomes σ'_r.

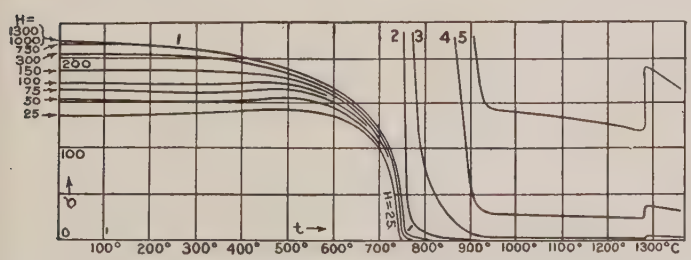

FIG. 10.—Specific magnetization (σ) of mild steel 38 (14). Curves 2, 3, 4, 5 represent portions of curve 1 with ordinates magnified 10, 100, 1000, and 5000 times, respectively; *v. also* Table 5.

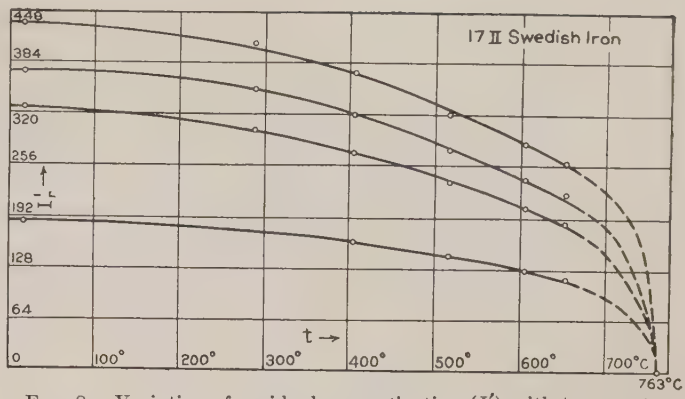

FIG. 8.—Variation of residual magnetization (I'_r) with temperature (49). The specimen is magnetized to a certain value of I_r when at room temperature and in zero field. It is then heated in zero field to several successively higher temperatures and at each the magnetization (I'_r) remaining is measured. Thus a curve for each initial value of I_r is obtained; *cf.* Table 5.

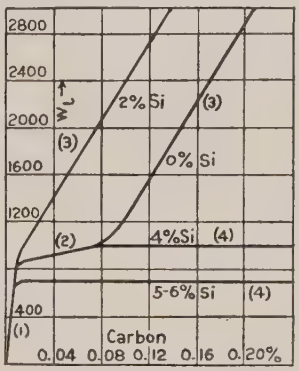

FIG. 11.—Effect of C and of Si upon hysteretic loss (94). Effect of other impurities has been eliminated. $B_{max.} = 10\,000$. In region (1), C is in solution, $dW_l/dC = 100\,000$; in (2), C is in form of Fe_3C, $dW_l/dC = 2\,500$; in (3) C is in form of pearlite, $dW_l/dC = 16\,500$; in (4), C exists as graphite, $dW_l/dC = 0$; unit of C = 1 %.

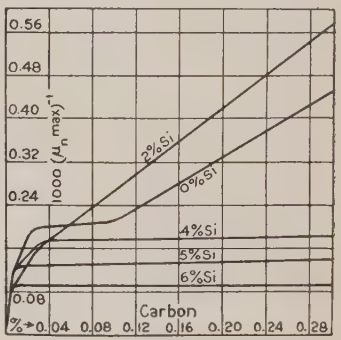

FIG. 13.—Effect of C and of Si upon permeability (94). Not corrected for size of grain; *cf.* Figs. 14, 15.

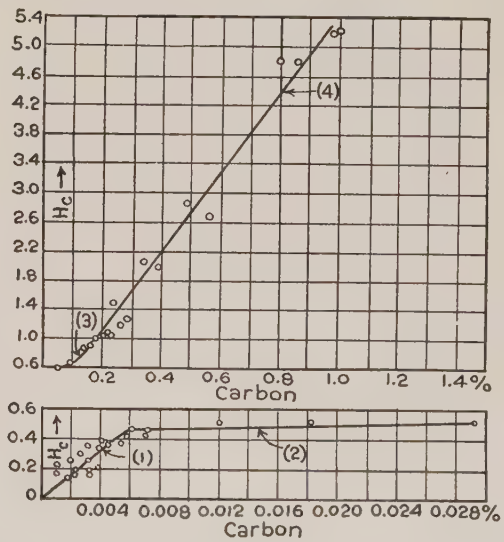

FIG. 12.—Effect of C upon coercive force (94). Not corrected for size of grain. In region (1), C is in solution, $H_c = 80$C; in (2) $dH_c/dC = 2.5$; in (3), cementite, $dH_c/dC = 0.8$; in (4), pearlite, $dH_c/dC = 5.4$; unit of C = 1 %; *v. also* Table 8.

TABLE 5.—(*Continued from p. 376*)

38	σ, Specific magnetization (14); *see* Fig. 10				
H \ t	20.0°C	275.0°C	477.0°C	601.0°C	688.0°C
750	215.7	207.1	188.9	164.0	126.8
1000	216.2	207.5	189.5	164.0	127.1
1300	216.3	207.5	189.6	164.0	127.1

38	σ, Specific magnetization (14); *see* Fig. 10				
H \ t	720.0°C	740.4°C	744.6°C	748.2°C	752.2°C
15	82				
25	84.5	46.0	27.0	6.5	
50	88.4	50.5	29.5	8.7	
75	91.0	53.0	31.0	10.0	
100	92.9	55.2	32.5	11.5	
150	94.4	57.1	34.6	14.0	3.5
300	97.8	58.5	39.2	19.4	5.3
750	100.1	61.3	45.4	29.2	12.2
1000	100.4	62.3	47.6	31.1	15.0
1300	100.7	64.0	50.1	37.3	18.2

38	σ, Specific magnetization (14); *see* Fig. 10				
H \ t	756.4°C	760.5°C	764.4°C	767.9°C	780.4°C
100	0.74	0.45	0.34	0.27	0.145
150	1.11	0.67	0.51	0.40	0.20
300	2.22	1.35	1.02	0.81	0.43
750	5.55	3.38	2.55	2.03	1.09
1000	7.4	4.5	3.4	2.7	1.45
1300	9.62	5.85	4.42	3.51	1.88

Electrolytic Iron

TABLE 6.—MAGNETIC PROPERTIES

For properties in very weak and in very intense fields, *see* Tables 3 and 4; for impurities, *see* Table 1

Key	Remarks
1.1	Heraeus. Fused in vacuum. Very pure; the mere traces of impurities contained in it are too small to be measured by the usual methods. At H = 16 820, $\sigma_{17°C}$ = 217.87; from an experimental study of the laws of approach to absolute saturation as H and T are varied, and by an extrapolation from H = 18 550 and T = 100°K to $H = \infty$ and T = 0°K, it was found that σ_∞ = 221.92; hence $\sigma_\infty \times$ atomic weight = 12 390 = 11 × 1 126 that is, the magnetic moment of the Weiss magneton is 1 126, *cf.* **146.1,** Table 19, p. 403, *see also* p. 345 (80).
3	Merck. Fused in H. Tabular values have been corrected for thermal expansion, d_{20} = 7.854 g/cm³; σ measured for H = 8 800, 10 500, 12 400, and 13 500, and σ_∞ obtained by extrapolating (σ, H^{-1}) curve to $H = \infty$ (53).
4	Fused in N in crucible of calcined magnesia. Using H = 1 700 to 20 000, found (83) $\sigma_{\infty,20.3°K}$ = 1.0175 $\sigma_{\infty,20°C}$; data corrected for thermal expansion (83). (No other data given.)
6	Fused in vacuum and annealed; C = 0.0015%.
7	Fused in vacuum and annealed; C = 0.0017%.
8	Fused in vacuum and annealed; C = 0.0018%.
10	Fused in vacuum, forged, annealed from 900°C, cooling to 200°C in 48 hr. Before forging, C = 0.006%; after, C = 0.0125.
13	Annealed from 800°C, C = 0.012%.

TABLE 6.—(*Continued*)

Key	Remarks
15	Plate, C = 0.024%; d = 7.876 g/cm³; σ_∞ = 218.4 after correction for effect of C, Si, Mn; **15**$_c$ = unannealed, **15**$_{a_1}$ = after first annealing in vacuum (800°C for 24 hr), **15**$_{a_{13}}$ = after 13th annealing (830°C), rapid cooling. After 5th annealing (920°C, rapid cooling), μ_n(max.) = 11 600, H_c = 0.225, B_r = 5 000.

Key =	**6**	**7**	**8**	**10**	**15**$_c$	**15**$_{a_1}$	**15**$_{a_{13}}$
H	B_n, Normal induction						
0.2	6 700	2 400	1 500				
0.4	12 900	10 200	9 900				
0.5				6 090	180	7 500	2 350
1	14 600	12 700	14 100	9 500	600	10 240	4 850
2				12 350			
4	15 400	13 900	15 500				
8				15 590			
20	16 400	15 000	16 400	16 200	15 300	16 200	15 850
100	18 400	17 200	18 200	17 950	18 380	18 050	17 700
% C	0.0015	0.0017	0.0018	0.006	0.024	0.024	0.024
μ_n(max.)	41 500	27 300	24 900	12 950	1 850	14 600	4 900
B_μ				6 550			
$B_{max.}$	10 000	10 000	10 000	15 000	19 710	19 450	18 520
B_r				9 940	11 450	10 850	850
H_c	0.17	0.21	0.23	0.34	2.83	0.375	0.155
W	505	647	735	1 990*			
Lit.	(94)	(94)	(94)	(90)	(22)	(22)	(22)

* For $B_{max.}$ = 10 000, W = 1 060.

Key =	**15**$_c$	**15**$_{a_1}$	**15**$_{a_{13}}$
H	μ_n, Permeability (22)		
0.25			4 000
0.5	360	15 000	4 700
0.75	467	12 400	4 867
1.0	600	10 240	4 850
1.5	1 010	7 600	4 733
2.5	1 748	5 120	4 280
5	1 784	2 894	2 900
10	1 285	1 550	1 535
20	765	810	792.5
50	343.0	342.0	334.4
100	183.8	180.5	177.0
150	127.7	125.8	123.5
200	98.55	97.25	
300	68.83	69.00	
500	43.26	43.34	
1 000	22.52	22.57	
2 000	11.81	11.81	
3 000	8.21	8.21	
4 000	6.405	6.405	
4 500	5.802	5.811	
μ_n(max.)	1 850	14 600	4 900
1000η	3.08	0.78	
H_c	2.8	0.37	0.15
B, Cyclic induction (22)			
±200	±19 710	±19 450	
+150	+19 160	+18 870	+18 520
100	18 510	18 150	17 700
50	17 470	17 230	16 770
25	16 480	16 580	16 100
10	15 240	15 920	15 520
5	14 170	15 320	15 120
2.5	13 200	14 400	12 850

TABLE 6.—(*Continued*)

Key =	15_c	15_{a1}	15_{a13}
H	B, Cyclic induction (22)		
+ 1	12 270	13 020	6 300
0	11 440	10 850	+ 850
− 0.25	11 200	+ 9 400	− 350
− 0.5	10 930	− 6 500	− 1 600
− 0.75	10 620	− 8 900	− 2 700
− 1.0	10 300	−10 000	− 3 850
− 1.5	9 420	−11 400	− 6 000
− 2.5	+ 3 100	−12 800	−10 200
− 5	− 7 770	−14 460	−14 500
− 10	−12 760	−15 500	−15 350
− 20	−15 300	−16 200	−15 850
− 50	−17 150	−17 100	−16 720
−100	−18 380	−18 040	−17 700
−150	−19 160	−18 870	−18 520
B_r	11 440	10 850	850

13	μ_n, Permeability (68)								H_m*
t \ H	0.2	0.5	1	1.5	2	3	10	60	
−190	60	90	100	140	190	430	1130	286	6.9
−121	65	120	250	250	700	1000	1200	284	5.4
− 60	70	190	400	400	1100	1800	1300	283	4.2
+ 23	80	260	500	870	1900	2600	1400	281	2.9
102	100	400	800	2200	3150	3130	1420	280	2.4
203	160	600	1200	4000	4350	3630	1430	275	1.8
308	200	800	1900	5400	4850	3760	1440	270	1.45
403	260	1200	5500	5740	4900	3780	1360	270	1.25
498	425	2600	7000	6140	5160	3830	1320	266	1.00
547	900	4000	7000	6000	5050	3710	1290	265	0.90
596	1200	4400	6800	5300	4950	3610	1290	255	0.85
642	1800	5600	6600	5740	4800	3500	1240	242	0.80
688	2600	6400	6300	5540	5500	3230	1170	220	0.75
724	3200	8400	6100	4800	4050	2950	1040	186	0.44
752	5000	9200	6100	4600	3650	2600	880	153	
781	2400	4200	2800	2140	1700	1260	430	78	

* H for μ_n (max.).

13 (68) (Cycle $H = \pm 90$)					3* (53)			
t	W	B_{90}†	B_r	H_c	t	σ_∞	t	σ_∞
−190	26 900	17 600	11 300	4.00	−188	220.9	645	147.7
−120	24 150	17 600	12 300	3.55	− 78	219.0	656	144.0
− 60	21 200	17 500	13 200	2.97	+ 16	216.2	662	142.9
+ 23	17 490	17 400	13 600	2.31	105	213.3	670	137.8
102	14 320	16 900	13 440	1.93	181	210.4	671	138.8
203	9 670	16 150	12 920	1.48	265	205.7	679	133.1
308	7 630	15 960	12 400	1.39	337	200.8	682	131.3
402	6 990	15 900	11 400	1.32	426	192.2	700	120.5
498	5 080	15 840	9 930	0.87	499	183.7	718	106.2
550	4 260	15 640	9 340	0.86	526	179.3	724	105.0
596	3 420	14 880	8 290	0.83	562	173.4	747	83.5
640	3 040	14 390	7 860	0.75	603	161.7	751	75.1
685	2 640	13 050	6 800	0.60	630	154.6	759	62.1
724	1 610	11 090	5 280	0.44	631	153.7	761	58.8
752	1 020	8 760	3 470	0.25	632	151.9	769	40.1
768	564	5 140	1 030	0.14	642	148.1	772	24.0

* *See also* Table 4. † For $H = 90$.

Carbon Irons and Steels

INTRODUCTION

In carbon irons and in carbon-silicon irons, the C may exist in one or more of three states. If the amount is small, the C is in solution; in this form it has a very great effect upon the magnetic properties. In larger amounts, the excess is precipitated as Fe_3C, at first in isolated masses of cementite, later as pearlite. In still larger amounts, the excess is precipitated as graphite; as graphite, it has scarcely any effect upon the magnetic properties. Mild steel contains only a small amount of C, and when annealed from about 900°C, the C is in the form of pearlite. Hard steel, or martensite, contains more C. Steel containing 0.85% C is a eutectoid; under suitable heat treatment it forms a material of homogeneous composition; there is no segregation of either ferrite or cementite. For effect of C and of Si upon permeability, *see* Fig. 13.

The magnetic quality of a material may be expressed by the hysteretic loss (W) per cm³ per cycle of amplitude $B_{max.}$ (say, $B_{max.} = 10\,000$), by the coercive force (H_c) for $B_{max.}$, or by the maximum reluctivity ($1/\mu_n$ max.) (*cf.* Figs. 12, 13).

Effect of C and Impurities upon Hysteretic Loss.—If W_l refers to the condition of very large grains, and if N = number of visible grains per mm² when the surface is polished and etched, then if all the C is dissolved, $W = W_l + 65\sqrt{N}$; if cementite, pearlite, or graphite is present, $W = W_l + 3N$. For a carbon iron, or for a carbon-silicon iron, containing C% of C and no other impurity, $W_l = a + b(C - d)$, where a, b, d depend upon the Si content; *see* Table 7 and Fig. 11.

TABLE 7.—EFFECT OF C UPON HYSTERETIC LOSS (94)

$W_l = a + b(C - d)$; unit of C, of Si = 1% (*v. also* Fig. 11)

Si	Range of C	a	b	d	State of carbon
0	0	0.0082_2	0	100 000	0 Dissolved
	0.01	0.08	850	2 250	0.0085 Dissolved and cementite
	0.10	0.90	1 033	16 500	0.09 Dissolved, cementite, and pearlite
2	0	0.0082_2	0	100 000	0 Dissolved
	0.01	0.50	900	16 500	0.009 Dissolved and pearlite
4	0	0.0082_2	0	100 000	0 Dissolved
	0.01	0.079	850	2 250	0.0085_5 Dissolved and cementite
	0.079	1.0	1 009	0	0 Dissolved, cementite, and graphite
6	0	0.0065_5	0	100 000	0 Dissolved
	0.01	1.0	700	0	0 Dissolved and graphite

Small amounts of S, Mn, and P increase W_l by the amounts (ΔW) indicated by the following equations (94), the symbol denoting the percentage of the corresponding element: If Si = 0, and approximately if Si < 2, $\Delta W = 195 + 18\,000S + 1\,000Mn + 13\,000(P - 0.015)$, provided $S \leq 0.10$, $Mn \leq 1.0$, $P \leq 0.015$; if $0.015 < P \leq 0.14$, the coefficient (13 000) of last term must be replaced by zero. If Si = 4, and approximately if $4 \leq Si \leq 6$, $\Delta W = 12\,000S + 800Mn - 4\,000P$. The presence of P is undesirable if Si = 0, but desirable if Si = 4 to 6.

TABLE 8.—COERCIVE FORCE (H_c): EFFECT OF C AND QUENCHING TEMPERATURE (t_q) (22)

Unit of C = 1% by weight

C \ t_q	750°C	800°C	850°C	900°C	950°C	1000°C	1100°C
0.068	1.80	2.34	4.48	17.1	15.1	11.7	13.2
0.110	3.72	4.61	3.83	17.9		12.4	15.7
0.155	5.43	8.10	9.15	26.0	25.8	25.0	25.0
0.208	6.74	14.3	25.7	27.1	27.0	26.0	25.5
0.234	7.28	13.2	23.2	21.6	16.5	17.8	19.5
0.445	25.3	35.6	36.7	34.8	35.0	35.0	32.9
0.475	26.8	34.4	34.2	34.2	33.2	32.7	30.6
0.695	37.3	46.8	47.4	47.4	47.3	45.7	41.1
0.708	46.0	46.1	46.2	46.2	45.2	44.5	40.3
0.710	31.6	46.7	46.5	46.8	45.6	44.2	40.4

TABLE 8.—(*Continued*)

C \ t_q	750°C	800°C	850°C	900°C	950°C	1000°C	1100°C
0.800	42.5	48.2	47.5	47.0	45.9	44.7	42.2
0.994	48.9	55.6	48.6	46.2	45.8	42.9	41.0
1.105	40.1	60.6	58.2	59.2	55.9	53.8	47.1
1.575	54.0	61.0	61.6	59.7	56.4	44.1	36.4
1.775	52.0	59.7	62.2	67.0	70.1	69.1	47.7

Also (94), if C < 0.006, $H_c = 80C$; 0.006 < C < 0.09, $H_c = 80C + 0.8(C - 0.006)$; 0.09 < C, $H_c = 80C + 5.4(C - 0.09)$; *see* Fig. 12.

Cementite (35).—Fe_3C; $d = 7.07$, $\sigma_\infty = 135$, $\Theta = 215$°C.

Pearlite (22).—If the pearlite contains p% C, $d_{red.} = 7.876 - 0.03p$; $\rho_{red.} = 10.5 + 3p + 2p^2$ and $H_c = 0.7 + 7.5p$ if $p \leq 0.9$; if $p \geq 1$, for ρ, and >0.9, for H_c, the increase is less rapid than is indicated by equation. $4\pi I_{\infty(red.)} = 21\,620 - 1\,580p$ if $p < 0.96$, $= 20\,100 - 930p$ if $p > 0.96$; from $B_{max.} = 20\,000$, B_r varies unsystematically around 10 000.

Martensite (22).—(1) Quenched at 850°C. If p_d% of dissolved C and p_c% of C in form of cementite, $d_{red.} = 7.876 - 0.14p_d - 0.03p_c$, $\rho_{red.} = 10.3 + 1.6p_d + 3p_c + 23p_d^2 + 2p_c^2$ if $p_c \leqq 0.9$, if $p_c \geq 1$, the increase is less rapid. If $p(\equiv p_c + p_d) < 1.2$, $4\pi I_{\infty red.} = 21\,620 - 3\,200p$; if $p > 1.2$, the decrease is less rapid; for aged material, $1\,000\beta = -0.63 + 0.42p$, $\beta = 0$ if $p = 1.5$. (2) Quenched at 1100°C. $d_{red.} = 7.876 - 0.08p$ if $p < 1$; $\rho_{red.} = 10.3 + 9.3p + 7.4p^2$ if $p < 1.8$; $4\pi I_{\infty(red.)} = 21\,620 - 2\,060p$ if $p < 1.1$; for aged material, $1\,000\beta = -0.50 + 0.34p$.

TABLE 9.—ANNEALED CARBON IRONS: PRINCIPAL MAGNETIC CONSTANTS

$\kappa_n^{-1} = a + bH$ if H is great; a derived from observations at $H \leq 1000$ gauss; for composition, *see* Table 1

Key	% C	t_a	$B_{max.}$	B_r	H_c	μ_n(max.)	I_∞	a
			$H_{max.}$ = 150 gauss [(11), except **43** (64)]					
14	0.018	930	18 740	11 680	3.1	5 320	1 703	0.0104
31	0.14	930	18 240	9 980	3.3	2 990	1 722	0.0232
35	0.23	870	18 010	10 010	4.5	2 090	1 688	0.0133
36	0.32	870	17 790	9 830	5.0	1 560	1 670	0.0147
40	0.52	820	17 310	9 410	6.1	1 180	1 626	0.0186
43	0.85		15 260	11 100	6.9			
44	0.88	760	16 050	10 610	8.5	830	1 583	0.0316
51	1.28	760	15 130	10 730	8.3	880	1 537	0.0530
52	1.32	760	14 990	10 530	7.5	920	1 507	0.0431
55	1.55	760	14 190	9 390	7.5	900	1 528	0.0579
57	1.60	760	13 850	8 990	11.0	470	1 534	0.0537
			$H_{max.}$ = 150 gauss [(22); except **68**, $H_{max.}$ = 200 (23)]					
16	0.027		18 850	9 850	0.76	6 400	1 683	
18	0.044		19 100	11 050	0.37	14 800	1 704	
28	0.085		18 620	10 250	0.885	5 700	1 702	
34	0.23	930	18 050	10 600	2.35	2 180	1 664	
41	0.69	930	17 000	11 100	6.29	880	1 615	
47	0.99	930	16 440	9 950	7.50	660	1 592	
56	1.57	930	15 000	10 300	10.23	530	1 550	
59	1.78	930	14 500	10 000	12.52	415	1 517	
68	3.109		11 920	5 300	4.6	620	1 333	

TABLE 10.—QUENCHED AND DRAWN CARBON IRONS: PRINCIPAL MAGNETIC CONSTANTS (11)

$\kappa_n^{-1} = a + bH$ if H is great; a derived from observations at $H \leq 1000$ gauss; for material and impurities, *see* Table 1; *see also* Figs. 14, 15, 16 and Table 11.

t_d	$B_{max.}$*	$B_{max.}$†	B_r†	H_c†	μ_n(max.)	I_∞	a	$\frac{B_m H_c}{1000}$†
	36, 0.32 % C; quenched at 900°C; drawn to t_d, °C (2 specimens)							
‡	16 470	21 450	12 950	18	333	1 660	0.014	386.5
100	16 240	21 200	12 300	21	317	1 610	0.016	445.5
170	16 290	21 250	12 550	19.5	339	1 640	0.015	414.5
230	16 790	21 520	13 520	19	38.1	1 650	0.010	409
270	17 030	21 790	13 550	16	462.5	1 674	0.010	348.3
350	17 300	21 540	14 100	15	472	1 660	0.011	323.2
450	17 350	21 440	15 300	14				
500	16 750	21 000	15 060	14	551	1 620	0.014	294
700	16 780	20 940	15 000	8	915	1 616	0.020	167.5
‡	16 040	21 680	12 860	20	290	1 676	0.015	433.6
150	16 570	21 660	12 840	15	346	1 670	0.015	325
200	16 510	21 440	12 900	21	354	1 658	0.015	451
250	17 050	21 740	13 100	16	388	1 674	0.015	348
300	17 170	21 520	13 420	16	425	1 650	0.011	344.6
400	17 270	21 540	14 710	16	477	1 660	0.010	345
470	17 250	21 440	15 100	16	514	1 660	0.015	343.2
600	17 230	21 490	15 350	10	834	1 660	0.014	214 9
	37, 0.39 % C; quenched at 800°C; drawn to t_d, °C							
‡	16 120	21 630	12 450	19	303.5	1 670	0.015	411.5
150	15 850	20 940	12 000	16	306	1 746	0.028	335.3
200	16 310	21 440	12 500	20.5	332	1 660	0.017	440
250	16 950	21 740	12 800	18.5	370	1 668	0.018	402.5
300	17 130	21 740	13 340	18	400	1 680	0.012	391.5
400	17 180	21 420	14 360	16	458	1 650	0.011	343
470	17 080	21 340	14 940	18	452	1 660	0.012	384
600	16 950	21 460	15 080	10	656	1 680	0.020	214.6
	44, 0.88 % C; quenched at 800°C; drawn to t_d, °C (2 specimens)							
‡	7 990	17 100	7 700	56	80	1 446	0.100	958
100	9 870	18 100	8 100	43	107	1 500	0.070	778.4
170	8 510	17 050	7 710	48	86.5	1 410	0.089	819
230	12 950	19 720	10 220	41	158.5	1 540	0.032	809
270	15 400	21 040	10 900	27	266	1 680	0.020	568.3
350	16 830	20 720	13 780	24	319.5	1 596	0.011	498
450	16 290	20 420	14 580	30	262	1 590	0.020	611.5
500	15 530	19 820	14 480	28	276	1 550	0.028	556
700	15 450	19 840	13 800	14	521.5	1 560	0.020	278
‡	8 000	17 080	7 700	54	80.5	1 440	0.095	923
150	8 130	16 840	7 500	56	81.5	1 414	0.098	944
200	7 800	17 140	8 000	51	85.7	1 408	0.078	874
250	14 080	20 340	11 000	39	182	1 580	0.025	794
300	16 450	20 660	13 120	27.5	292	1 596	0.011	502
400	16 550	20 340	14 060	30	389	1 576	0.016	611
470	15 850	20 140	14 600	32	262	1 562	0.016	645
600	15 540	20 020	14 280	20.5	368	1 573	0.022	411
	45, 0.96 % C; quenched at 800°C; drawn to t_d, °C							
‡	8 990	17 780	7 900	44	93.4	1 510	0.103	783
100	6 800	16 490	7 350	47	67.5	1 390	0.090	775.8
170	8 200	15 490	6 750	44	86.6	1 270	0.081	682
230	12 250	18 690	9 150	36	153	1 470	0.038	673
270	13 600	19 240	9 900	31	202	1 510	0.027	596
350	14 900	19 640	11 740	32	240	1 526	0.023	628.5
450	14 550	19 240	12 500	34	199	1 520	0.040	654
500	14 180	18 740	12 800	29.5	255	1 468	0.032	552.5
700	13 880	18 360	12 220	15.5	390	1 450	0.038	285

* Cyclic; $H_{max.} = 100$ gauss.
† Cyclic; $H_{max.} = 1000$ gauss.
‡ Not drawn.

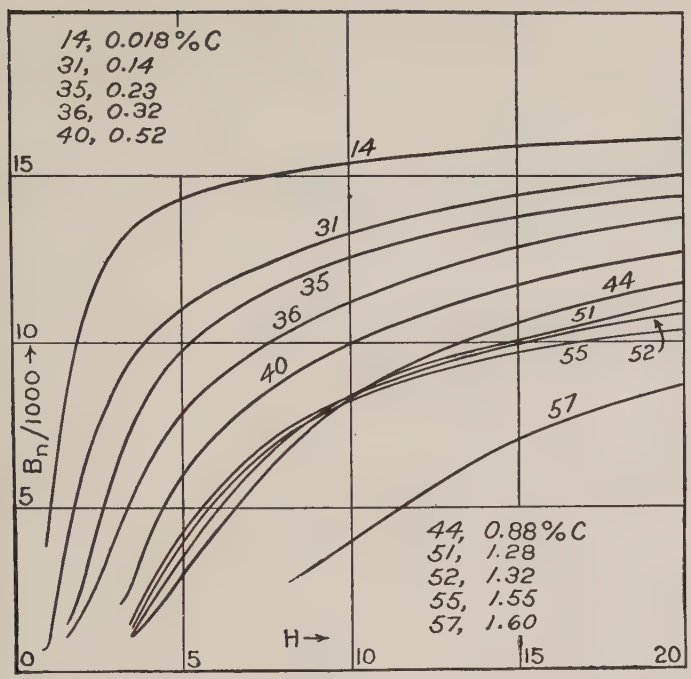

Fig. 14.—Effect of C upon normal induction (11). Specimens annealed in vacuum. On the curves are the key numbers (Table 1) of the materials.

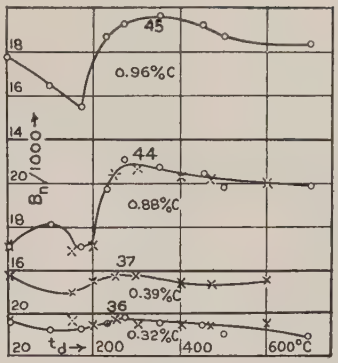

Fig. 15.—Effect of drawing temperature (t_d) upon normal induction (11). $H_{max.} = 1000$. On the curves are the key numbers (Table 1) of the materials. Quenching temperature = t_q; for **36**, t_q = 900°C; **37**, t_q = 850°C; **44, 45**, t_q = 800°C.

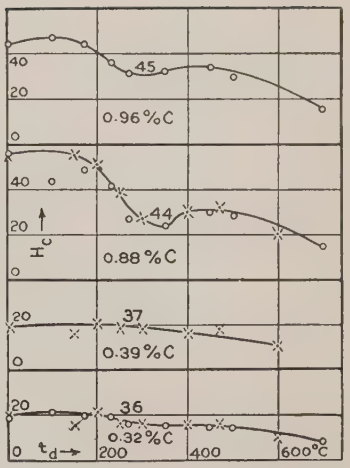

Fig. 16.—Effect of drawing temperature (t_d) upon coercive force (11).
Conditions as for Fig. 15, *q.v.*

Table 11.—Normal and Cyclic Magnetization of Carbon Irons: Various Heat Treatments

For material and impurities, *see* Table 1; t_a = 900°C, except as indicated

Key	16_c	16_a	18_c	18_a	28_c	28_a
H	μ_n, Normal permeability (22)					
0.25	1 200	1 240	960	12 400	1 400	1 800
0.5	1 800	2 000	1 200	14 200	2 600	3 100
0.75	3 000	4 530	1 530	11 920	4 140	4 940
1.0	5 000	6 350	2 300	10 200	4 600	5 650
1.5	5 330	5 600	4 030	7 820	4 200	5 460
2.5	4 200	4 220	3 720	5 370	3 360	4 320
5	2 580	2 590	2 430	3 000	2 210	2 710
10	1 460	1 460	1 410	1 570	1 330	1 500
20	785	810	775	805	740	785
50	340	340	335	340	330	335
100	179	181	180	183	175	178
150	124.7	125.7	125.0	127.3	122.7	124.1
300	67.3	67.3	68.0	68.1	66.7	67.3
500	42.4	42.3	42.9	42.9	42.2	42.8
1 000	22.12	22.04	22.35	22.32	22.10	22.34
2 000	11.60	11.57	11.70	11.69	11.61	11.69
3 000	8.07	8.06	8.14	8.14	8.08	8.14
4 500	5.71	5.71	5.76	5.76	5.72	5.76
	B, Cyclic induction (22)					
150	18 700	18 850	18 750	19 100	18 400	18 620
100	17 970	18 130	18 000	18 300	17 600	17 800
50	17 030	17 220	17 000	17 120	16 500	16 800
25	16 240	16 530	16 070	16 430	15 600	16 070
10	15 300	15 700	14 930	15 850	14 600	15 350
5	14 500	14 220	14 040	15 500	13 300	14 740
2.5	13 700	12 920	13 000	15 100	11 900	13 740
+ 1	12 700	11 600	11 900	13 700	10 160	12 300
0	10 400	9 850	10 600	11 050	7 850	10 250
− 0.25	10 850	8 950	10 150	+ 9 400	6 800	9 500
− 0.5	10 200	7 100	9 630	− 6 300	4 700	8 250
− 0.75	9 200	+ 1 000	9 000	− 9 000	+ 1 200	+ 4 400

TABLE 11.—(*Continued*)

Key	16_c	16_a	18_c	18_a	28_c	28_a
H	B, Cyclic induction (22)					
− 1.0	+ 3 500	− 5 400	+ 8 100	−10 200	− 2 300	− 1 900
− 1.5	− 7 050	− 8 200	− 1 500	−11 730	− 5 000	− 6 450
− 2.5	−10 400	−10 500	− 8 560	−13 400	− 7 600	−10 130
− 5	−12 900	−12 940	−11 940	−15 000	−10 630	−13 360
− 10	−14 600	−14 630	−14 020	−15 680	−13 180	−14 880
− 20	−15 700	−16 100	−15 450	−16 130	−14 760	−15 680
− 50	−16 900	−17 120	−16 830	−17 100	−16 300	−16 700
−100	−17 930	−18 130	−17 980	−18 280	−17 520	−17 770
−150	−18 700	−18 850	−18 750	−19 100	−18 400	−18 620
B_r	11 400	9 850	10 600	11 050	7 850	10 250
H_c	1.06	0.76	1.46	0.37	0.83	0.885
μ_n(max.)	5 400	6 400	4 200	14 800	4 600	5 700
1000α	1.31	1.05	1.57	0.54	1.62	1.10
$4\pi I_{\text{sored.}}$	21 200	21 180	21 419	21 419	21 249	21 400

24I* (65); μ_n				**24**I* (65); I, Cyclic magnetization					
H	μ_n	H	μ_n	H	$4\pi I$	H	$4\pi I$	H	$4\pi I$
0.14	1 200	1.91	6 410	±164.5	±19 100	−0.22	+5 800	− 0.77	− 5 010
0.23	3 020	3.67	3 740	+106.8	+18 260	−0.36	2 540	− 0.87	− 6 820
0.30	5 300	7.79	1 920	71.8	17 600	−0.41	1 280	− 1.08	− 8 720
0.36	7 000	20.7	770	37.3	16 730	−0.45	370	− 1.42	−10 760
0.41	8 090	71.2	248	20.7	16 120	−0.50	− 470	− 1.91	−12 210
0.54	9 560	106.8	172	7.32	15 230	−0.53	− 970	− 3.54	−13 730
0.73	9 500	164.5	117	2.10	14 300	−0.56	−1 360	− 7.80	−14 920
0.97	9 120	260.1	78.0	0.28	11 790	−0.60	−2 310	−20.7	−15 980
1.38	7 820	322.2	64.4	− 0.09	8 890	−0.67	−3 390	−71.7	−17 570

* For anhysteretic magnetization and differential permeability, *see* Table 2.

Key	**34**		**41**		**47**		**56**	
t_a	930°		930°		930°		930°	
t_q		850°		850°		850°		850°
H	μ_n, Normal permeability (22)							
1.0	1 000		280		200			
1.5	1 600							
2.5	2 200		340		230		210	
5	1 840		740		370		270	
10	1 200		850		655		500	
20	710		600		530		470	
50	320		290		280		250	
100	172.0		160.8		155.0		141.3	
150	120.3		113.3		109.6		100.0	
200	93.0		87.3		85.0		77.0	
300	65.2		61.6		59.7		53.3	
500	41.4	40.8	39.2	35.4	38.0	31.3	34.1	27.2
1 000	21.75	21.52	20.75	19.53	20.23	17.70	18.55	15.62
2 000	11.45	11.37	11.03	10.60	10.82	9.79	10.18	8.85
3 000	7.97	7.93	7.73	7.43	7.61	6.96	7.24	6.37
4 000	6.23	6.20	6.06	5.84	5.98	5.50	5.72	5.09
4 500	5.65	5.62	5.50	5.32	5.42	5.02	5.21	4.65
5 500						4.29		3.99
6 500						3.79		3.52
	B, Cyclic induction (22)							
+300		19 280		17 200		14 250		12 650
200		18 220		16 120		12 870		11 470
150	18 050	17 500	17 000	15 330	16 440	11 910	15 000	10 740
100	17 300	16 540	16 200	14 200	15 630	10 720	14 300	9 820
50	16 200	15 100	15 130	13 660	14 470	9 120	13 320	8 600
25	15 370	13 860	14 230	11 600	13 500	8 080	12 550	7 720
10	14 270	12 750	13 230	10 730	12 120	7 300	11 700	7 100
5	13 300	12 280	12 500		11 300		11 200	
2.5	12 450		11 900		10 700		10 900	

TABLE 11.—(*Continued*)

Key	34		41		47		56	
t_a	930°		930°		930°		930°	
t_q		850°		850°		850°		850°
H	B, Cyclic induction (22)							
+ 1	11 600		11 450		10 270			
0	10 600	11 600	11 100	10 000	9 950	6 700	10 300	6 650
− 1.0	9 000		10 650		9 520			
+ 1.5	+ 8 000							
2.5	− 2 400		9 500		8 800		9 700	
5	− 8 600	10 880	+ 4 800	9 620	+ 6 800		8 650	
10	−11 950	9 650	− 7 300	9 200	− 4 650	6 000	+ 900	6 100
20	−14 100	+ 3 600	−11 950	+ 8 220	−10 600	+ 5 080	− 8 800	5 450
50	−15 970	−13 450	−14 600	− 3 300	−13 850	− 400	−12 570	+ 2 600
75	−16 650	−15 220	−15 500	−11 100	−14 820	− 6 300	−13 500	− 3 700
100	−17 200	−16 150	−16 080	−13 200	−15 500	− 9 100	−14 130	− 7 580
150	−18 050	−17 300	−17 000	−14 900	−16 440	−11 450	−15 000	−10 020
200		−18 140		−15 860		−12 670		−11 200
300		−19 280		−17 200		−14 250		−12 650
B_r	10 600	11 600	11 100	10 000	9 950	6 700	10 300	6 650
H_c	2.35	23.2	6.29	47.4	7.50	48.6	10.23	61.6
μ_n(max.)	2 180		880		660		530	
μ_0	170	76	126	54	132		143	
$4\pi I_{\infty obs.}$	20 900	20 770	20 220	19 450	19 860	18 220	19 300	16 710
$4\pi I_{\infty red.}$	20 970	21 040	20 340	19 770	20 060	18 420	19 530	16 940
ρ_{20}	10.95	12.75	13.21	21.17	15.57	34.74	16.53	39.57
$1000\alpha_{red.}$	5.56	4.75	4.95	3.03	4.35	1.70	4.25	1.58
$d_{red.}$	7.858		7.843		7.848	7.747	7.828	7.743

43†B_n, Normal induction (47)

H \ t_d	20°C‡	100°C	170°C	200°C	230°C	250°C	270°C	300°C
20	700	900	1 300	1 200	1 550	2 350	2 350	2 650
50	3 250	3 300	4 850	5 850	9 600	12 750	12 920	14 000
100	8 950	8 900	10 450	11 400	14 370	16 300	14 950	16 630
150	11 380	11 450	12 520	13 230	15 900	17 450	17 120	17 700
200	12 750	12 700	13 630	14 220	16 850	18 150	17 700	18 250
300	14 050	13 950	14 900	15 320	17 950	19 100	18 350	18 850
500	15 550	15 550	16 050	16 660	19 460	20 200	19 380	19 650
700	16 500	16 550	16 850	17 420	20 220	20 700	19 750	20 150
1 000	17 450	17 500	17 650	18 250	20 850	21 250	20 200	20 700
1 500	18 580	18 550	18 620	19 150	21 630	22 000	20 900	21 400
2 000	19 350	19 380	19 400	19 900	22 280	22 600	21 420	21 950
2 500	20 000	20 100	20 100	20 600	22 800	23 150	21 920	22 400

H \ t_d	350°C	400°C	430°C	450°C	470°C	500°C	600°C	700°C
20	3 550	3 550	3 550	2 850	2 750	3 350	4 000	7 100
50	14 350	14 450	14 650	14 250	13 850	13 950	13 650	14 050
100	16 560	16 580	16 800	16 600	16 450	16 250	15 870	15 700
150	17 400	17 550	17 650	17 400	17 420	17 120	16 800	16 450
200	18 000	18 050	18 150	18 100	18 000	17 700	17 300	16 950
300	18 900	18 650	18 800	19 100	18 750	18 550	18 000	17 600
500	19 400	19 400	19 500	19 250	19 180	19 300	18 900	18 700
700	19 900	19 880	20 000	19 900	19 650	19 720	19 400	19 250
1 000	20 360	20 400	20 500	20 400	20 120	20 250	20 020	19 850
1 500	21 050	21 100	21 200	21 100	20 850	21 000	20 700	20 680
2 000	21 660	21 650	21 750	21 650	21 500	21 620	21 450	21 350
2 500	22 250	22 120	22 200	22 150	22 050	22 200	22 050	21 950

43§B_n, Normal induction (47)

H \ t_d	20°C‡	102°C	170°C	200°C	230°C	250°C	270°C	300°C
20	780	700	840	950	2 200	3 800	2 400	3 700
50	3 180	3 050	3 550	5 350	9 900	13 650	13 400	14 350
100	9 150	8 750	9 000	11 600	14 360	16 600	16 580	16 900
150	11 500	11 250	11 200	13 500	15 900	17 820	17 830	18 000
200	12 700	12 450	12 370	14 600	16 500	18 500	18 500	18 570

† Oil-quenched at 800°C. ‡ Undrawn. § Water-quenched at 800°C.

TABLE 11.—(*Continued*)

43§B_n, Normal induction (47).—(*Continued*)

H \ t_d	20°C‡	102°C	170°C	200°C	230°C	250°C	270°C	300°C
300	14 250	14 000	13 700	15 600	17 900	19 300	19 300	19 300
500	15 700	15 750	15 250	16 800	18 940	20 100	20 100	19 900
700	16 700	16 700	16 050	17 500	19 500	20 500	20 600	20 300
1 000	17 650	17 700	16 850	18 250	20 100	21 000	21 100	20 800
1 500	18 800	18 800	17 800	19 150	20 900	21 800	21 800	21 500
2 000	19 600	19 650	18 600	19 800	21 500	22 400	22 300	22 100
2 500	20 250	20 300	19 250	20 400	22 000	22 800	22 800	22 600

H \ t_d	370°C	410°C	450°C	475°C	500°C	600°C	700°C
20	3 500	3 900	3 000	2 600	1 550	7 500	7 000
50	14 350	15 000	14 250	13 450	12 650	14 100	13 350
100	16 900	17 050	16 800	16 500	16 070	16 200	15 100
150	17 700	18 000	17 600	17 500	17 080	17 170	15 900
200	18 200	18 500	18 080	18 000	17 650	17 620	16 400
300	19 000	19 100	18 800	18 800	18 450	18 250	17 100
500	19 500	19 750	19 500	19 700	19 250	19 150	18 000
700	19 950	20 200	19 900	20 100	19 720	19 700	18 600
1 000	20 380	20 700	20 400	20 570	20 300	20 300	19 200
1 500	21 050	21 400	21 100	21 200	21 000	21 000	20 000
2 000	21 650	21 950	21 400	21 700	21 600	21 650	20 700
2 500	22 220	22 400	21 900	22 130	22 120	22 250	21 200

43_q§ (47)		**43_q‖ (64)**				**43_a (64)**			
H	B_n	$H_{max.}$	$B_{max.}$	B_r	H_c	$H_{max.}$	$B_{max.}$	B_r	H_c
14	540	42	2 720	950	9	32	12 080	7 500	5.0
30	1 320	86	8 050	4 540	22	92	15 020	10 980	6.5
56	3 880	137	11 210	6 900	34	120	15 570	11 650	9.0
88	8 040	190	12 680	7 600	44.5	183	16 280	12 100	10.0
118	10 220	220	13 160	7 700	46.0	246	16 990	12 500	10.5
156	11 700	304	14 360	8 150	49.5	325	17 690	13 000	11.0
232	13 250	410	15 240	8 300	50.0	418	18 140	12 620	11.5
318	14 400	485	15 690	8 440	50.5	500	18 380	13 100	12.0
430	15 320	570	16 290	8 550	52.0	680	18 970	13 240	12.0
535	15 960	670	16 580	8 600	52.0	850	19 380	13 480	12.5
685	16 660	748	16 660	8 600	52.0	1 080	19 820	13 600	14.0
860	17 300	842	17 220	8 750	52.0	1 260	20 350	13 650	12.5
1 090	17 900	920	17 420	8 800	53.0	1 520	20 890	14 050	13.0
1 380	18 570	1 050	18 040	8 900	52.5	1 840	21 240	14 000	13.0
1 710	19 100	1 310	18 570	9 000	52.5	2 090	21 930	14 310	13.0
2 000	19 520	1 500	18 750	9 100	53.0	2 300	21 940	14 300	13.0
2 420	20 150	1 710	19 000	9 120	52.5	2 430	21 860	14 200	13.0
2 630	20 440	2 000	19 540	9 300	52.5				
		2 290	19 930	9 380	52.0				
		2 420	19 970	9 300	52.5				

§ Water-quenched at 800°C. ‖ Oil-quenched at 800°C.

59 (22)				**68 (22)**				
t_a	930°			H	Unannealed		Annealed	
t_q		850°	1100°		B_n	μ_n	B_n	μ_n
H	μ_n							
2.5	150			2.5	235	94	900	360
5	190			5	570	114	2 950	590
10	325			10	1 960	196	5 150	515
20	405			20	4 700	235	6 820	340
50	240			50	7 520	150	8 620	172
100	135.4			100	9 320	93.2	9 950	99.5
150	96.7			150	10 500	70.0	11 020	73.6
200	75.0			200	11 430	57.2	11 920	59.6
300	53.0			300	12 550	41.8	12 800	42.7
500	33.9	26.7	21.5	500	13 900	27.8	14 130	28.3

TABLE 11.—(*Continued*)

59 (22)				68 (22)				
t_a	930°			H	Unannealed		Annealed	
t_q		850°	1100°		B_n	μ_n	B_n	μ_n
H	μ_n							
1 000	18.40	15.32	12.60	1 000	15 900	15.9	16 200	16.2
2 000	10.09	8.70	7.28	2 000	17 840	8.92	18 120	9.06
3 000	7.17	6.27	5.32	3 000	19 180	6.39	19 490	6.50
4 000	5.65	5.00	4.28	4 000	20 350	5.09	20 670	5.18
4 500	5.15	4.57	3.93	4 500	20 870	4.65	21 200	4.72
5 500		3.94		5 500	21 920	4.0	22 260	4.06
6 500		3.49		6 500	22 920	3.53	23 250	3.58
B, Cyclic induction				B, Cyclic induction				
300		12 600	6 530	200	11 430		11 920	
200		11 520	5 760	150	10 570		11 080	
150	14 500	10 800	5 300	100	9 520		10 020	
100	13 800	9 870	4 730	50	8 220		8 750	
50	12 780	8 630	3 950	25	7 180		7 820	
25	11 950	7 820	3 500	10	6 170		6 800	
10	11 100	7 250	3 110	+ 5	5 700		6 200	
5	10 700			0	5 100		5 300	
+ 2.5	10 400			− 2.5	4 670		+ 4 450	
0	10 000	6 820	2 800	− 5	4 180		− 1 800	
− 5	8 740			− 10	+ 1 750		− 5 150	
− 10	+ 4 650	6 270	2 480	− 20	− 4 160		− 6 820	
− 20	− 6 900	5 660	+1 950	− 50	− 7 380		− 8 620	
− 50	−11 820	+ 2 700	− 440	−100	− 9 200		− 9 950	
− 75	−12 920	− 3 450	−2 400	−150	−10 500		−11 020	
−100	−13 540	− 7 300	−3 600	−200	−11 430		−11 920	
−150	−14 500	−10 020	−4 830					
−200		−11 200	−5 580					
−300		−12 600	−6 530					
B_r	10 000	6 820	2 800	B_r	5 100		5 300	
H_c	12.52	62.2	47.7	H_c	11.4		4.6	
μ_n(max.)	415			μ_n(max.)	240		620	
μ_0	95	37		1000η	11.4		4.37	
$4\pi I_{\infty obs.}$	19 000	16 460	12 110	$4\pi I_{\infty obs.}$	16 420		16 750	
$4\pi I_{\infty red.}$	19 100	16 760	12 410					
ρ_{20}	17.61	41.65	48.58					
$1000\alpha_{red.}$	4.17	1.54	1.87					
$d_{red.}$	7.799	7.720	7.730					

Magnet Steels

INTRODUCTION

The special magnet steels and those other steels which possess similar properties include: Carbon steels **26, 33, 39, 42, 46, 50, 53, 54, 58**; manganese steel **70**; cobalt steels **80** to **85**, **87** to **90**; molybdenum steels **91** to **94**; nickel steel **101**; and tungsten steels **136** to **144**. For composition and designation, *see* Table 1.

For cobalt-manganese steels, H_c is great and is a maximum for Mn = 4 to 5%; it increases with % Co. An addition of 5% Cr increases H_c, makes the material very hard so that it becomes saturated only in intense fields (25). For the "K.S." steel (**84**) containing W, H_c is very great. Best quenching temperature is 950°C; best quenching bath is a heavy oil. Within the range of composition stated in Tables 1, 13, the magnetic properties do not vary greatly with the composition. For example, four specimens of different composition gave, respectively, for $H_{max.}$ = 1500, I_r = 920, 841, 828, and 620, H_c = 226, 221, 245, and 257. For bars, length = l, diameter = d, I_r is independent of l/d if $l > 20d$, *see* Fig. 17 (33).

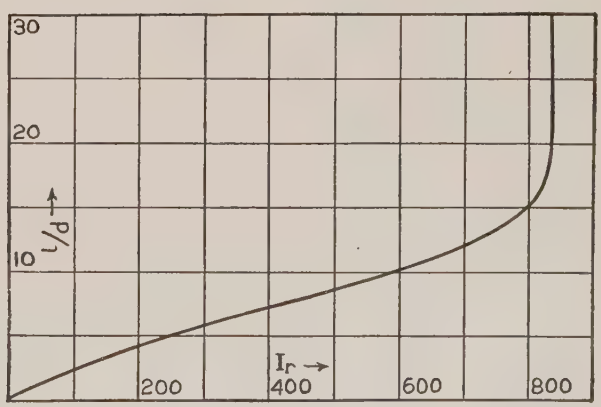

FIG. 17.—Residual magnetization of circular bars: Variation with length (l) and diameter (d) (33). Material is **84**, K. S. magnet steel.

TABLE 12.—CYCLIC MAGNETIZATION

For composition, *see* Table 1

Rings* [15]; *see also* Figs. 18, 19

H	I	H	I	H	I	H	I	H	I
26_q		**33_q**		**39_q**		**$42I_q$**		**$42II_q$**	
505	1 560	505	1 590	515	1 525	515	1 230	505	1 155
256	1 495	490	1 580	510	1 520	268	1 070	245	1 070
167	1 440	248	1 500	260	1 425	160	990	134	965
78.5	1 330	162	1 450	167.5	1 365	+ 78.6	850	+ 75	875
42	1 220	+ 76.8	1 320	+ 79.3	1 230	0	605	0	670
+ 16.1	980	0	770	0	835	− 33.3	370	− 16.7	595
0	625	− 4.2	460	− 13.9	360	− 46.3	150	− 26.7	535
− 1.8	480	− 6.9	+ 64	− 16.7	+ 137	− 51.7	+ 11.3	− 43.0	370
− 2.5	293	− 7.7	− 36.5	− 19.6	− 14.5	− 58.6	− 192	− 48.5	260
− 2.9	113	− 11.4	− 340	− 28.8	− 350	− 78.5	− 580	− 53.3	140
− 3.2	+ 0.8	− 23.6	− 825	− 46.5	− 875	−135	− 880	− 57.6	+ 22.1
− 3.5	− 36	− 56.0	−1 200	− 82.5	−1 150	−254	−1 080	− 58.1	− 3.7
− 4.2	− 181	− 84.5	−1 300	−136.5	−1 285	−505	−1 230	− 74.7	− 442
− 5.5	− 350	−120.5	−1 350	−260	−1 409	−515	−1 230	−137.5	− 860
− 8.3	− 685	−137.5	−1 390	−510	−1 525			−245	−1 040
− 21.0	− 925	−250	−1 480	−515	−1 525			−495	−1 155
− 52.8	−1 190	−485	−1 580					−505	−1 155
−135.5	−1 400	−505	−1 590						
−258	−1 490								
−505	−1 560								
I_r	625		770		835		605		670
H_c	3.2		7.4		19.3		52		58
W	28 000		68 000		108 000		170 000		217 000

H	I	H	I	H	I	H	I
46_q		**50_q**		**70_q**		**101_q**	
495	1 175	535	1 200	460	1 390	455	990
253	1 075	270	1 080	270	1 325	242.5	930
165	1 010	161.5	1 015	260	1 320	137.5	860
+ 78.2	875	+ 78.5	890	140	1 245	+ 78.5	805
0	640	0	645	134.5	1 230	0	640
− 16.0	530	− 14.5	555	80.8	1 140	− 29.6	490
− 32.8	292	− 21.9	500	+ 59.2	1 095	− 39.0	353
− 44.0	102	− 33.3	347	0	860	− 42.8	290
− 46.4	64.7	− 51.7	+ 20	− 16.2	705	− 47.1	199
− 48.7	+ 14.0	− 58.7	− 128	− 27.3	+ 395	− 49.0	153.5
− 52	− 43.7	− 79.2	− 550	− 34.1	− 139.3	− 53.5	+ 10.5
− 60.6	− 262	−124	− 865	− 43.5	− 700	− 58.6	−153.5
− 78.5	− 570	−199	−1 025	− 52.5	− 870	− 78	−525
−139	− 915	−291	−1 090	− 99.5	−1 130	−121	−750
−255	−1 075	−515	−1 200	−159	−1 240	−240	−905
−495	−1 175	−535	−1 200	−264	−1 330	−450	−980
				−515	−1 390	−455	−990
				−460	−1 390		
I_r	640		645		860		640
H_c	50		53		33		54
W	165 000		182 000		142 000		177 000

H	I	H	I	H	I	H	I	H	I
136_q		**143_q**		**143_q†**		**143_q‡**		**84_a [33]**	
510	1 240	515	1 240	495	1 515	495	1 230	19	281
269	1 115	270	1 160	280	1 420	257	1 160	30	805
157.5	1 060	166.5	1 120	164	1 350	+168	1 110	78	1 227
+ 53.8	930	153.5	1 115	+ 52.1	1 180	0	850	247	1 372
0	800	105	1 060	0	900	− 39.0	670	377	1 410
− 26.9	685	98	1 055	− 16.2	630	− 58.5	450	675	1 450
− 53.8	480	55	985	− 21.6	350	− 60.5	410	776	1 465
− 59.3	+ 352	33.3	940	− 25.8	+ 5.8	− 67.2	+ 136.5	960	1 479

TABLE 12.—(*Continued*)

H	I	H	I	H	I	H	I	H	I
136$_q$		**143$_q$**		**143$_q$**†		**143$_q$**‡		**84$_a$** (33)	
− 70.1	− 28.6	+ 23.9	920	− 26.9	− 122.5	− 72.3	− 161	1 322	1 499
− 78.2	− 358	0	850	− 31.7	− 630	− 96.5	− 840		
− 89.0	− 635	− 25.0	705	− 55.0	−1 050	−136.5	− 970		
−113.0	− 855	− 44.6	545	−113	−1 255	−257	−1 125		
−161.5	− 995	− 56.6	415	−290	−1 425	−495	−1 230		
−291	−1 115	− 72.7	+ 23.7	−490	−1 510				
−490	−1 240	− 74.2	− 89	−495	−1 515				
−510	−1 240	− 81.0	− 323						
		− 89.0	− 624						
		−113.3	− 880						
		−161.5	−1 050						
		−183	−1 085						
		−269	−1 140						
		−505	−1 240						
		−515	−1 240						
I_r	800	850		900		850			
H_c	69	73		26		70		*See below*	
W	260 000	280 000		115 000		265 000			

84$_q$, t_q = 950°C; *see also* Fig. 20

Bars§ (33)		Isthmus method (64)							
H	I_n	$H_{max.}$	$B_{max.}$	B_r	H_c	$H_{max.}$	$B_{max.}$	B_r	H_c
53	54	26	210	0		665	13 780	8 360	194
91	107	48	450	80	5.5	850	14 710	8 650	201
200	365	84			9	1 060	15 530	8 800	205
295	909	100	1 140	200		1 380	15 510	8 780	210
344	998	149	2 280	580	16	1 675	17 190	8 850	210
581	1 171	224	4 660	2 100	48	1 975	17 750	8 840	211
870	1 266	296	9 080	5 610	116	2 260	18 370	8 900	212
982	1 293	410	11 340	7 200	160	2 500	18 720	8 900	215
1 281	1 346	490	12 290	7 800	178				

* Quenched at 800°C, excepting **26** at 1000°C, **33** at 850°C, and as noted.
† Not quenched.
‡ Section = 0.25 cm².
§ Normal magnetization; H = effective field intensity, corrected for demagnetizing field; bars, length = 20 cm; diameter = 0.5 cm.

TABLE 13.—COERCIVE FORCE AND RESIDUAL MAGNETIZATION AND THEIR VARIATION WITH HEAT TREATMENT

See also Table 12; for composition, *see* Table 1; temperatures are °C

Cobalt steels (25); *see also* Figs. 20, 21, 22

Key	% C	% Mn	% Co	Key	% C	% Mn	% Co	Key	% C	% Mn	% Co	% Cr
87	0.83	4.8	35	**80**	1.37	4.7	10	**81**	1.22	3.9	10	5.4
88	1.12	4.7	35	**83**	1.16	4.4	22	**82**	1.11	3.5	20	5.1
89	1.24	4.0	35	**85**	1.15	4.4	33	**90**	1.11	3.5	36	4.8
84	K. S. magnet steel 0.4 to 0.8% C, 30 to 40% Co, 1.5 to 3% Cr, 5 to 9% W; Figs. 20, 22, Table 12											

Quenched	Water		Oil		Magnetically very hard			
Key	H_c	B_r	H_c	B_r	Key	$H_{max.}$	B_r	H_c
87	132	8270	158.0	9350	**90**	540	8820	217.2
88	149.3	9260	156.0	9580	**90**	820	9210	226.0
89	149.2	9710	132.3	9720	**90**	1110	9310	227.1
t_q	825°		850°		875°		900°	
Key	H_c	B_r	H_c	B_r	H_c	B_r	H_c	B_r
80	70.7	3800	71.8	2650	63.3	1890	61.8	76
83	126.4	8300	130.8	8240	118.0	7860	110.5	797
85	131.2	8390	164.0	9310	160.4	8890	150.3	1224
81	110.0	8790	114.9	7760	113.2	7650	112.0	754
82	114.2	9850	155.0	9430	153.3	9270	158.8	1322
90	94.2	9530	200.1	9140	203.8	9130	207.8	1672

TABLE 13.—(*Continued*)

Square Bars [15]; l = 20 cm, section 1 × 1 cm

t_d	τ_d	t_q	H_c	I_r
42, Carbon steel, C = 0.84%				
Undrawn			51	422
100	3 hr		45	415
100	10		45	396
100	16		44	397
100	24		44	390
150*	8.5		37	363
250†	7.5		28	310
Total loss at 100°			13%	8%
Total loss at 200°			41%	27%
91, Mo = 3.5%, C = 0.51%				
		850°	60	530
92, 93, Mo = 3.4 to 4.0%, C = 1.24 to 1.25%				
Undrawn			82.5	496
60	7 hr		79.7	494
60	42		79.8	490
		800	82	480
		800	85	530
94, Mo = 3.9%, C = 1.72				
Undrawn			79	429
100	3 hr		73	433
100	10		71	418
100	16		70	416
100	24		70	413
150*	8.5		50	417
250†	7.5		40	382
Total loss at 100°			12%	4%
Total loss at 200°			50%	11%
		770	73	510
		830	79	415
		800	78	560

Key	τ_d	t_q	H_c	I_r
136		850	66	510
137		830	68	500
138		800	69	540
139		850	51	460
140		850	74	530
141		830	65	550
142		1000	50	320
143, W = 5.5%, C = 0.59%				
t_d	τ_d	t_q	H_c	I_r
Undrawn			69	574
100	3 hr		65	583
100	10		63	549
100	16		62	544
100	24		61	540
150*	8.5		46	465
250†	7.5		37	401
Total loss at 100°			12%	6%
Total loss at 200°			17%	33%
Undrawn			70.7	561
60	7 hr		69.7	572
60	42		69.9	564
Undrawn			70.7	579
60	52 hr		69.6	579
		770	72	560
		770	74	560
Quenched in H_2O‡			73	550
Quenched in Hg			78	540
144, W = 7.7%, C = 1.96%				
Undrawn			79.8	336
60	7 hr		78.3	340
60	42		79.0	339
Unquenched			45	350
		800	85	370

* In addition to 24 hr at 100°C. † In addition to 24 hr at 100°C and 8.5 hr at 150°C. ‡ 740° < t_q < 825°C; within this range, actual temperature is unimportant.

TABLE 14.—EFFECT OF MECHANICAL SHOCK [15]

Square bars 20 cm long, side of section = S mm; undrawn; dropped on pavement of hard sandstone, alternately with bar vertical, fall = 85 cm, and bar horizontal, fall = 30 cm. Initial magnetization (before being dropped) = I_r(max.). After being dropped N times, additional dropping produced no further change in I; if I_e is this equilibrium value, I_r(max.) − I_e = Δ × I_r(max.). Drawing at 100 or at 200°C produces little change in Δ and N; for composition, *see* Table 1.

Key	S	H_c	I_r(max.)	Δ	N
26	10	3	27	>83%	>75
33	10	11	117	>45	>95
39	10	23	210	23	30
42	10	54	398	3.2	15
46	10	54	386	3.4	20
50	10	58	451	4.8	20
53	8.5	59	358	3.5	15
54	8.5	60	366	5.5	20
58	8.5	46	274	8.5	20
84*			854	6.3	850*
92	10	85	520	3.2	10
94	10	73	448	2.9	10
140	10	74	580	3.0	20

TABLE 14.—(*Continued*)

Key	S	H_c	I_r(max.)	Δ	N
143	10	72	570	6.0	45
143	10	73	560	5.0	50
143	8.5	94	680	2.6	10
144	10	86	390	1.5	5

* Falls on concrete; equilibrium not attained for N = 200; *see* Fig. 23.

TABLE 15.—EFFECT OF EXTERNAL MAGNETIC FIELD [15]

Bars are initially magnetized to I_r(max.); H = field required to reduce magnetization to I = 0.90 I_r(max.); for composition, *see* Table 1.

Key	**39**	**93***	**143***	**143†**	**144***
H_c	21	80	70	71	78
H	3.5	21.0	13.5	13.0	27.5

* Drawn at 60°C. † Undrawn.

TABLE 16.—TEMPERATURE COEFFICIENT

Bars 20 cm long, square section, side = 1 cm, I = 0.90 I_r(max.), centigrade temperature; for composition *see* Table 1

84	K. S. steel [33], $dI/dt = 0.00021I$, 28°C < t < 100°C
91 to 94	Molybdenum steel [15], $dI/dt = 0.0003I$
143	Tungsten steel [15] $dI/dt = 0.0002I$

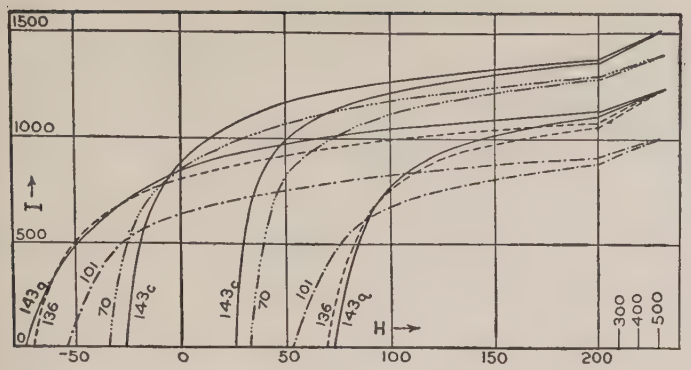

FIG. 18.—Carbon magnet steels. Cyclic magnetization [15]. Data are from Table 12; on the curves are the key numbers (Table 1).

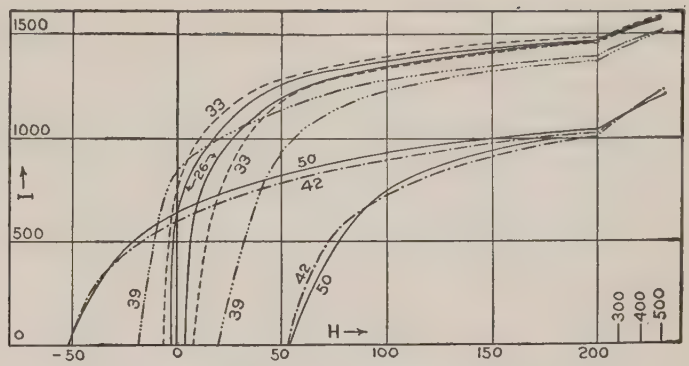

FIG. 19.—Special magnet steels: Cyclic magnetization [15]. Data are from Table 12; on the curves are the key numbers (Table 1).

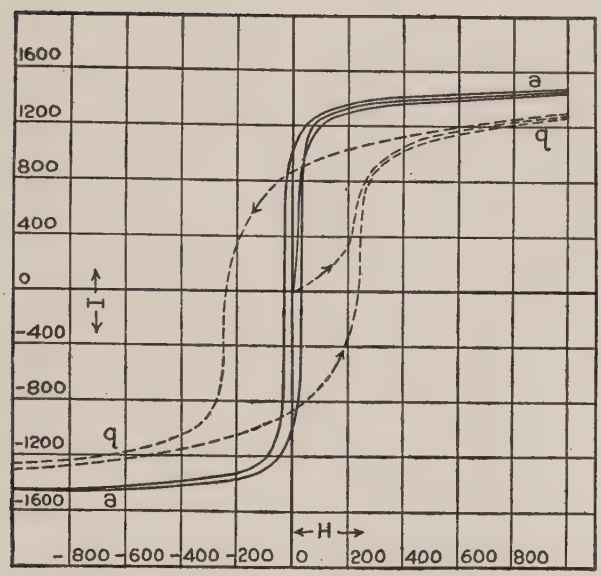

FIG. 20.—K. S. magnet steel: Cyclic magnetization [33]. Key number **84** (Table 1); *a* = annealed, *q* = quenched at 950°C, *cf.* Table 12.

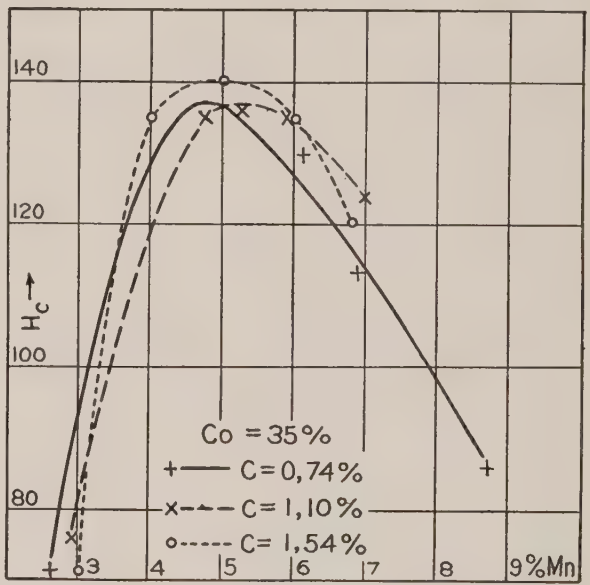

FIG. 21.—Cobalt steels: Effect of Mn upon coercive force [25].

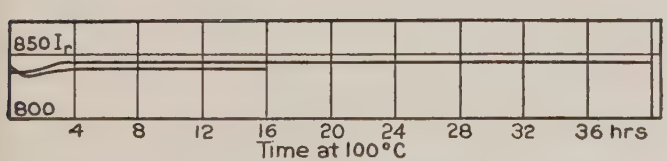

FIG. 22.—K. S. magnet steel: Aging at 100°C [33]. Two specimens; key number **84** (Table 1).

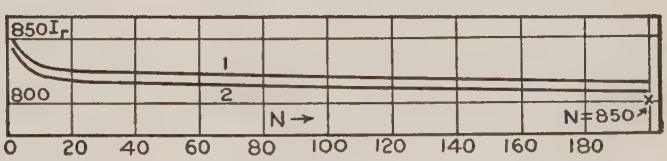

FIG. 23.—K. S. magnet steel: Effect of mechanical shock [33]. Key number **84** (Table 1). *N* = number of falls; height of fall = 100 cm; strikes on (1) wooden floor, (2) concrete floor.

Alloys of Iron

TABLE 17.—MAGNETIC PROPERTIES

For significance of key numbers, *see* Table 1; for carbon irons, *see* Tables 2 to 16

Al, Aluminium irons (23). Dissolved C increases H_c; the addition of Al tends to counteract this effect. Material annealed *in vacuo* and cooled slowly, except as otherwise indicated; $d_{red.} = 7.865 - 0.117p$, $p < 5.4$; $\rho = 9.9 + 11p$, $p < 4$; $\rho = 100$ approximately, if $p = 10$; $4\pi I_{\infty red.} = 21\,640 - 570p$, $p < 10$; $1\,000\alpha = 0.35$ if $p = 10$.

Admixture	H_c		Admixture		H_c			
% C	Dissolved	Cementite	% C	% Al	Before annealed	Annealed 1100°	Quenched	
0.12	20	1.60	0.12	0.52	1.20	1.04	11.7	
0.13	21	1.68	0.13	3.19	1.08	0.97	3.8	
0.15	23	1.83	0.15	5.66	1.77	1.60	2.6	
0.10	18	1.45	0.10	10.52	0.90	0.84	1.3	
Key	**77$_a$***	**77$_a$†**	**78$_a$***	**78$_a$†**	**79$_a$***	**79$_a$†**	**79$_a$‡**	**79$_a$†‡**
H	μ_n, Normal permeability							
0.25	1 600	1 600	680	1 280	800	240	800	720
0.5	1 800	2 500	760	1 800	860	260	840	840
0.7	2 270	3 600	830	2 270	1 130	320	930	1 010
1.0	2 450	5 000	930	2 860	1 230	360	1 000	1 200
1.5	2 600	5 600	1 070	3 580	1 270	410	1 010	1 290
2.5	2 480	4 420	1 260	3 150	1 140	620	910	1 240
5	1 870	2 600	1 180	2 090	880	1 160	720	960
10	1 240	1 380	890	1 270	640	950	530	680
20	710	730	590	690	435	580	365	445
50	315	310	275	300	240	270	210	229
100	169.7	164.2	152.2	160.0	138.8	146.2	129.3	131.0
150	118.5	114.8	106.2	111.1	98.9	101.8	93.1	92.8
300	63.3		58.3		50.7			
500	39.7		36.8		31.2			
1 000	20.8		19.07		16.16			
000	11.00		10.06		8.62			
3 000	7.68		7.05		6.10			
4 000	6.01		5.54		4.84			
4 500	5.47		5.02		4.42			
	B, Cyclic induction							
150	17 770	17 220	15 930	16 670	14 830	15 270	13 960	13 920
100	17 000	16 460	15 230	16 000	13 910	14 690	12 970	13 110
50	15 880	15 580	13 950	15 080	11 970	13 570	10 620	11 530
25	14 940	15 020	12 920	14 400	9 730	12 440	8 220	9 740
10	13 430	14 520	10 490	13 170	6 780	10 980	5 700	7 350
5	11 250	14 150	8 620	11 870	5 170	10 000	4 300	5 670
2.5	9 070	13 630	7 170	10 300	3 960	9 230	3 260	4 320
+ 1	7 050	12 920	5 900	8 700	2 020	8 560	2 430	3 370
0	4 900	11 700	4 700	6 900	2 150	7 940	1 680	2 350
− 0.5	2 920	10 270	3 870	5 300	1 360	7 580	1 020	1 500
− 0.75	+ 1 350	+ 6 800	3 360	3 720	800	7 350	+ 600	830
− 1.0	− 1 100	− 800	2 820	+ 950	+ 100	7 120	− 30	+ 60
− 1.5	− 3 300	− 7 050	+ 1 520	− 2 350	− 1 020	6 530	− 880	− 1 230
− 2.5	− 5 870	−10 720	− 1 520	− 5 950	− 2 520	+ 4 760	− 1 960	− 2 730
− 5	− 9 100	−12 800	− 5 470	− 9 530	− 4 300	− 3 360	− 3 440	− 4 670
− 10	−12 200	−13 570	− 8 840	−12 200	− 6 300	− 9 230	− 5 170	− 6 730
− 20	−14 250	−14 400	−11 700	−13 700	− 8 700	−11 470	− 7 280	− 8 880
− 50	−15 680	−15 500	−13 830	−14 970	−11 900	−13 440	−10 500	−11 450
−100	−16 970	−16 420	−15 220	−16 000	−13 880	−14 620	−12 930	−13 100
−150	−17 770	−17 220	−15 930	−16 670	−14 830	−15 270	−13 960	−13 920
B_r	4 900	11 700	4 700	6 900	2 150	7 940	1 680	2 350
H_c	0.91	0.96	1.99	1.08	1.10	4.19	0.84	0.90
μ_n(max.)	2 610	5 600	1 260	3 580	1 430	1 160	1 010	1 300
μ_0	213		196		234			
$4\pi I_{\infty obs.}$	20 100		18 150		15 540			
$4\pi I_{\infty red.}$	20 340		18 460		15 750			
$1000\eta_{max.}$	1.30	1.52	1.98	1.50	0.87	3.44		
ρ_{20}	35.43		64.33		98.03			
$1000\alpha_{red.}$	1.52		0.67		0.32			
$d_{red.}$	7.623		7.208		6.860			

* Rod, annealed from 800°C.
† Sheet, 0.5 mm, annealed from 800°C.
‡ Annealed from 1100°C.

B, Boron iron (91). Addition of a small amount of B improves the iron by reducing FeO; a larger amount has an unfavorable effect; B is added as a flux in the form of B_7O containing 20.3% B; *see* Fig. 24.

Co, Ferrocobalts. Fe_2Co is more magnetic than Fe (*see* Table 4); *see also* following table and Figs. 25, 26, p. 385 and Table 13 (80 to 90).

79*a* In an electric resistance furnace and a magnesia crucible, electrolytic Fe and pure Co from Merck were fused in hydrogen; I was measured from −188 to 1400°C, $8\,800 < H < 13\,500$ gauss; by extrapolation of (σ^2, H^{-1}) curve obtained σ_∞; σ corrected for expansion (53).

Co, %	d_{20}	σ_∞*	Θ, °C	Co, %	d_{20}	σ_∞*	Θ, °C
0	7.854	221	774	59.8	8.29	211	989
9.72	7.66	212	873	69.0	8.41	203	990
19.2	7.93	222	945	79.1	8.55	191	957
28.2	8.01	233	986	89.3	8.70	179	1037
38.1	8.09	233	995	100	8.87	168	1140
48.2	8.17	224	997				

* For $H = \infty$, $t = -188$°C (53).

86*II*, Ferrocobalt, 34% Co; essentially Fe_2Co (23)

Normal permeability				Cyclic induction			
H	μ_n	H	μ_n	H	B	H	B
2.5	1 580	150	149.7	±150	±22 450	− 1.5	+ 5 730
5	1 530	300	79.0	+100	+21 220	− 2.5	+ 1 650
7.5	1 320	500	48.2	50	18 640	− 5	− 7 000
10	1 147	1 000	24.6	25	16 220	− 10	−11 470
20	724	2 000	12.8	5	11 800	− 20	−14 480
50	366	3 000	8.88	0	8 230	− 50	−18 300
75	266.1	4 000	6.92	− 0.5	7 600	− 75	−19 960
100	211.0			− 1.0	6 800	−100	−21 100
μ_n(max.)	1 650	$4\pi I_\infty$	23 680	B_r	8 230	H_c	2.72
ρ_{20}	11.48	1 000α	2.2				

Cr, Chrome irons (45); material from Armstrong, Whitworth and Co.

Normal intensity of magnetization (I_n)

	Annealed from 900°C*					Quenched at 900°C*				
H / % Cr	10	40	60	100	150	10	40	60	100	150
1	460	844	940	1040	1117	60	588	796	960	1076
	480	878	978	1082	1159	40	504	762	944	1060
4.05	160	892	980	1078	1142	38	317	630	840	945
	125	878	970	1088	1158	24	270	590	820	935
8	88	790	888	984	1060	18	130	304	600	744
	78	778	878	980	1070	17	120	286	580	724
12	80	765	850	936	1008	20	112	235	485	653
	70	750	840	932	1018	13	100	210	470	638
16	70	635	710	780	850	17	84	162	360	508
	55	608	695	784	865	12	76	145	340	492
20	122	636	700	774	820	12	50	110	276	404
	106	625	698	782	832	12	42	98	258	390

	I_r, Residual magnetization†						H_c, Coercive force					
% Cr =	1	4.05	8	12	16	20	1	4.05	8	12	16	20
A‡	400	500	660	510	490	440	5	21	20	19	17	15
Q‡	660	600	580	435	340	320	28	39	46	54	56	44

* For each % Cr, the first line refers to 15°C, the second line to −190°C.
† For cyclic magnetization, $H_{max.} = 150$ gauss, room temperature.
‡ A = annealed from 900°C; Q = quenched at 900°C.

Cu, Iron-copper alloys. Alloy A (9): Electrolytic Fe and Cu were fused in magnesia crucible; annealed at 675°C; B_n is smaller if alloy is annealed at 1000°C or quenched at 900°C. Alloy B (61): Electrolytic Cu was fused with iron containing C = 0.08, Si = 0.01, Mn = 0.06, P = 0.01, S = 0.01, Cu = 0.03%; porcelain crucible, atmosphere of N. The Curie temperature (Θ) and the temperatures at which the $\gamma - \beta$ and $\delta - \gamma$ transformations occur (centigrade temperature) are shown in the table.

Alloy A (room temperature)					Alloy B			
H =	10	20	50	100	% Fe	Heating	Cooling	
% Cu	B_n, Normal induction					Θ, °C	$\gamma - \beta$, °C	$\delta - \gamma$
0.00	10 000	15 900	17 700	18 800	3	760		
0.09	5 700	13 200	16 800	18 300	5	763		
0.20	5 700	13 200	16 800	18 300	10	759		

TABLE 17.—(*Continued*)

Alloy A (room temperature) —(*Continued*)					Alloy B.—(*Continued*)			
H =	10	20	50	100	% Fe	Heating	Cooling	
% Cu	B_n, Normal induction					θ, °C	$\gamma - \beta$, °C	$\delta - \gamma$
0.42	10 900	14 900	17 100	18 500	20	763	795	
0.80	6 300	14 000	16 900	18 500	30	764	795	
1.01	6 300	13 200	16 500	18 000	40	764	798	
1.51	4 300	12 600	16 600	18 200	50	766	803	
2.00	5 000	12 600	16 400	18 200	60	766	804	
3.99	5 700	12 900	16 300	18 000	70	766	804	
5.07	4 300	12 300	16 100	17 600	96	763	810	1 462
6.16	4 300	12 000	15 500	17 400	98	763	826	1 439
7.05	3 000	10 400	15 400	17 200	99	764	844	1 432
94.34	0	0	200	50	100	773	875	1 420

Mn, Manganese irons (23). Properties are complex. Quenched alloys are more magnetic (μ_n greater) than those cooled slowly; for the former H_c attains 60, for the latter 130 gauss. If $12 < p < 14$, the alloy is practically nonmagnetic at room temperatures until after it has been chilled in liquid air; it is then magnetic. If $p > 14$, the alloy is not magnetic at room temperatures even after chilling in liquid air. If $p < 8$; $d_{20} = 7.873 - 0.008p$; from $p = 8$ to $p = 10$, d increases abruptly by 1.6%; if $p > 10$, d decreases less rapidly than is indicated by equation. If $p < 4$, $\rho = 10 + 5p$; for $p = 5.74$, $\rho = 36$; for $p = 7.81$, $\rho = 45$; if $10 < p < 16$, $\rho = 50.6 + 0.7\ (p - 10)$. After quenching at 800°C, $4\pi I_\infty = 21\,425 - 210p$, if $p < 7.8$; if $7.8 < p < 15$, $4\pi I_\infty = 19\,800 - 2\,830(p - 7.8)$; if $p = 15$, $4\pi I_\infty$ is practically zero; *see also* p. 385, Table 12, (**70, 80** to **90**), and Fig. 21.

Key	71_q	72_q	73_q	74_q	75_q	76_q	75_a	76_q	76_q
H	Quenched at 800°C						t_a = 800°C	t_q = 660°C	Precooled*
	μ_n, Normal permeability								
5	80	80	76	56	22	6.0	15	1.6†	2.0†
10	90	90	88	60	24	7.0	16.5	2.0†	3.0†
20	125	123	113	63.5	25	7.0	18	2.3†	5.5†
50	230.0	220.0	205.0	110.6	29.0	7.6	20.4	3.10†	10.8†
100	150.6	146.5	139.8	102.0	38.5	8.4	22.0	3.45†	15.1†
150	111.3	108.9	104.5	79.1	35.5	8.7	21.4	3.60	14.9
300	62.7	62.3	60.2	46.8	24.13	7.30	15.80	3.33	11.23
500		39.40	38.44	30.80	17.12	6.04	11.80		
1 000		20.94	20.48	16.88	10.14	4.27	7.37		
2 000		11.11	10.88	9.26	6.09	3.015	4.59		
3 000		7.760	7.603	6.590	4.533	2.477	3.527		
4 000		6.070	5.955	5.225	3.712	2.168	2.965		
5 000		5.054	4.964	4.396	3.210	1.966	2.612		
6 000		4.375	4.302	3.832	2.860	1.820			
6 500		4.112	4.048	3.616	2.725	1.759			
	B, Cyclic induction								
300	18 880	18 680	18 050	14 030	7 240	2 200	4 740	1 000	3 370
200	17 810	17 540	16 900	13 000	6 650	1 840	4 230	800	2 950
150	16 970	16 600	15 940	12 300	6 220	1 600	3 880	680	2 680
100	15 720	15 220	14 530	11 380	5 690	1 320	3 490	545	2 350
50	13 640	13 100	12 500	10 130	5 070	1 030	3 000	400	1 960
25	12 100	11 500	10 870	9 200	4 660	840	2 720	325	1 720
10	10 900	10 260	9 560	8 500	4 400	750	2 550	270	1 550
+ 5	10 380	9 700	9 100	8 230	4 280	700	2 480	255	1 490
0	9 700	9 050	8 600	7 900	4 150	660	2 400	230	1 430
− 5	9 000	8 380	8 000	7 500	4 020	620	2 270	215	1 360
− 10	8 170	7 500	7 300	7 080	3 880	580	2 100	195	1 290
− 20	+ 5 750	+ 5 000	+ 5 100	6 100	3 550	475	1 740	150	1 140
− 30	− 2 500	− 3 550	− 1 400	+ 4 600	3 150	360	1 380	+ 100	960
− 50	−11 360	−11 000	−10 250	− 3 000	+ 2 100	+ 80	+ 600	− 5	+ 450
− 75	−13 850	−13 400	−12 600	− 8 340	− 1 500	− 380	− 540	− 160	− 600
−100	−15 060	−14 650	−13 980	−10 200	− 3 670	− 720	−1 770	− 305	−1 380
−150	−16 700	−16 340	−15 680	−11 860	− 5 330	−1 260	−3 150	− 540	−2 240
−200	−17 680	−17 430	−16 800	−12 880	− 6 200	−1 660	−3 900	− 710	−2 720
−300	−18 880	−18 680	−18 050	−14 030	− 7 240	−2 200	−4 740	−1 000	−3 370
B_r	9 700	9 050	8 600	7 900	4 150	660	2 400	230	1 430
H_c	24.0	23.0	24.9	39.4	58.5	53.6	65.2	48.0	60.7

TABLE 17.—(*Continued*)

Key	71_q	72_q	73_q	74_q	75_q	76_q	75_a	76_q	76_q
	Quenched at 800°C						t_a = 800°C	t_q = 660°C	Precooled*
$B_rH_c/1000$	233	208	214	311	243	35	156	11	87
μ_n(max.)	235	226	205	116	40	9.0	22	3.6	15.2
μ_0‡		73	63	32.5	10				
$4\pi I_{\text{cobs.}}$		20 280	19 850	17 110	11 360	5 200	8 500		
$4\pi I_{\text{cred.}}$		20 570	20 270	17 750	11 700	5 350			
ρ_{20}	24.63	30.38	35.37	45.42	51.83	53.41	50.84		
$1000\alpha_{\text{red.}}$ §	3.03	2.67	2.38	2.06	2.00	1.86	2.00		
$d_{\text{red.}}$ §	7.8566	7.8550	7.8438	7.8451	7.9708	7.9826			

* Precooled to −78°C. † Deduced from hysteresis cycle. ‡ Before annealing. § After slow cooling.

Mo, Molybdenum steel. *See* Tables 13 to 16, **91** to **94.**

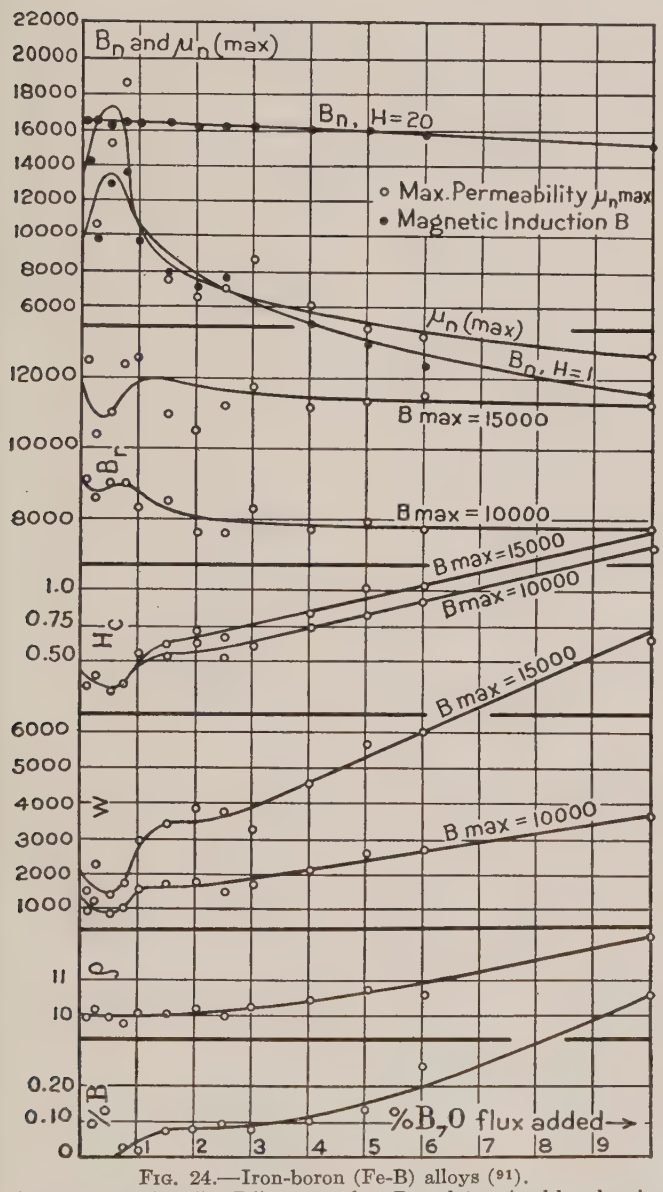

FIG. 24.—Iron-boron (Fe-B) alloys (91).
In lowest section, "% B" = actual % B as determined by chemical analysis of resulting alloy. Unit of ρ = 1 microhm-cm; of other quantities = 1 cgsm unit.

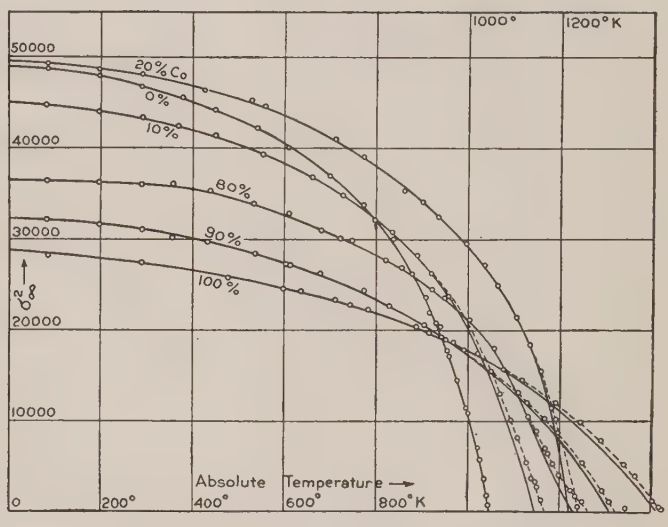

FIG. 25.—Ferrocobalts (Fe-Co): Variation of magnetization with absolute temperature (53); *v. also* Fig. 26.

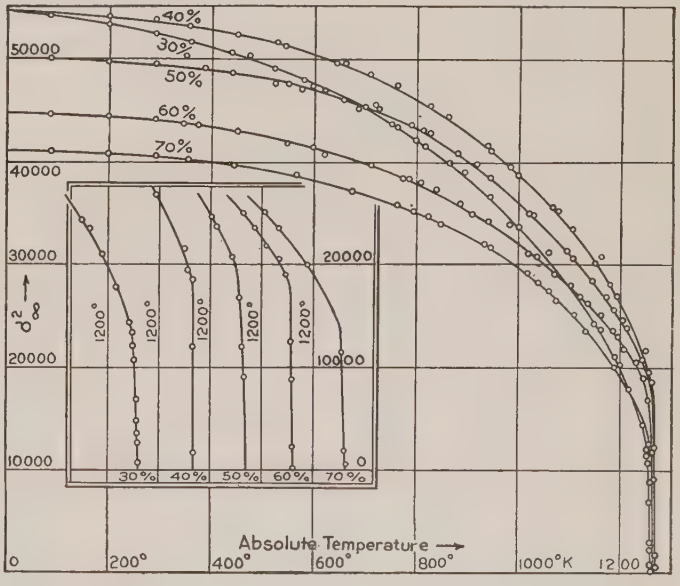

FIG. 26.—Ferrocobalts (Fe-Co): Variation of magnetization with absolute temperature (53); *v. also* Fig. 25.

Ni, Ferronickels. *See also* Table 12, **101.** The initial permeability (H very small) of ferronickels containing **from 30 to 90% Ni** exceeds that of pure Fe; it has a very marked maximum near 78.5% Ni. *See* Fig. 27. For permalloy, *see* p. 396.

95 In a high-frequency electric induction furnace, pure Ni and electrolytic Fe were fused *in vacuo.* The Ni was from Mond, and contained Ni, 99.89%; Cu, 0.004; Fe, 0.053; C, 0.045; S, tr.; SiO_2, 0.008. Θ_β = Curie point corresponding to transformation to state β; Θ_w is defined by $\chi(T - \Theta_w)$ = constant (*see* Curie point, p. 369), the material being in the γ-state (face-centered cube); and Θ_f = temperature of transformation ($\alpha - \gamma$) as determined by ferromagnetic method (**51**).

Temperatures t, Θ are °C

t	+16°	−79°	−188°	−273°*	Θ_β	Θ_w	Θ_f
% Ni	σ_∞						
0	217.4	219.7	221.1	221.5	771	−5500	
1.4	217.6	220.0	221.4	221.9	766	−3380	
3.5	218.4	221.3	223.0	223.5			
5.05	218.5	221.3	223.5	224.0	752	−2870	
6.9	218.1	221.8	223.6	224.2			
11.3	216.2	220.0	222.3	223.0		−1240	
15.9	213.7	217.9	221.4	221.8		− 646	
19.0	211.0	215.6	219.4	220.1		− 252	
25.2	200.9	207.1	211.1	212.1		− 12	
25.5	199.7	206.2	210.0	211.0			
29.7	185.3	191.3	197.0	198.7		+ 162	+120
31.3	179.6	186.9	192.4	194.1			
31.8	177.8	185.2	191.5	193.3		197	160
33.3	150.6	166.2	178.0	181.6			
33.8	148.1	164.2	176.7	180.2			
35.3	128.1	151.7	170.2	178.4		299	261
37.0	138.1	158.5	173.2	177.3		312	285
39.0	148.3	164.7	175.6	177.7		355	317
40.8	151.1	165.8	175.9	177.9		380	321
42.0	157.0	168.4	175.4	176.5		410	346
43.5	157.2	167.5	172.8	174.3		433	403
49.6	153.8	159.0	163.1	164.0		522	506
51.0	151.7	157.0	161.0	161.7			
57.7	141.8	145.3	147.8	149.0		600	590
67.0	127.5	129.9	131.9	132.3		622	612
80.2	99.7	101.3	102.1	102.4		599	576
87.7	82.9	84.3	85.0	85.4		539	511
100	55.1	56.8	58.1	58.4		382.0	360
100†	55.1	56.9	57.8	58.0			

* Extrapolated. † Ni from Merck.

Electrolytic Fe and electrolytic Ni were fused in magnesia crucible, pressure = 1 to 2 mm of mercury. The Fe and Ni used contained the following impurities (tr. = trace only):

	C	S	Si	Mn	P	Cu	Al	Ni	Fe	
Fe	0.014	0.003	tr.	tr.	tr.	tr.	0.005		99.978	%
Ni	0.030	0.006	0.040	tr.	0.001			99.673	0.250	%

These alloys and others prepared from them by adding known amounts of one, or more, other elements (Al, Mn, Si, or Ti) were studied. All were annealed at 900 to 1000°C and cooled slowly (24 hr) (**93**). In the following tables, the Ni refers to this 99.673% material.

Key	**96**	**99**	**102**	**104**	**106**	**109**	**112**
Ni =	0.50	1.96	3.85	5.68	7.33	9.61	11.10%
H	B_n, Normal induction						
0.2	600	200	100	200	100		
0.4	3 400	600	200	600	300		100
1.0	13 600	7 200	1 600	4 500	1 200	300	300
4.0	15 700	13 400	13 200	11 000	7 600	3 400	2 900
20.0	16 500	16 700	16 400	14 500	16 200	13 000	13 300
100.0	18 300	18 600	18 600	16 700	19 100	18 700	19 100
400.0	21 200	21 600	21 800	19 100	21 600	21 000	21 500
Annealed	920°	940°	902°	923°	1 064°	920°	923°C
μ_n(max.)	18 200	8 200	4 350	4 500	2 130	810	855
$B\mu$*	10 000	10 000	10 000	3 220	5 000	10 000	8 900
W†	1 175	1 900	3 300	2 440	4 225	9 270	9 450
H_c†	0.39	0.65	1.10	0.80	1.45	3.30	3.70

TABLE 17.—(*Continued*)

Key	115	117	123	125	127	128	129
Ni =	15.87	21.03	38.92	54.08	57.99	66.96	75.80%
H	B_n, Normal induction						
0.2			300	3 600	2 600	200	100
0.4			1 000	7 300	3 600	400	700
1.0	200	100	3 000	11 100	5 200	2 600	4 200
4.0	1 100	500	6 400	13 700	7 900	10 000	9 000
20.0	8 100	5 400	10 400	15 600	12 200	13 100	11 100
100.0	15 200	15 200	12 400	15 600	13 800	13 600	11 400
400.0	19 700	20 000	12 200	16 000	14 200	13 900	12 000
Annealed	923°	923°	923°	923°	923°	923°	931°C
μ_n(max.)	475	276	3 060	19 600	14 500	3 200	4 230
B_μ*	5 000	4 500	2 300	5 200	1 888	5 500	4 400
W†	13 080	30 000	1 030	580	194	1 330	627
H_c†	5.10	13.00	0.45	0.18	0.14	0.56	0.34

	Alloys containing 0.2% Al			Alloys containing 0.2% Ti			
Key	118	120	121	110	114	116	119
Ni =	23.8	25.1	29.8%	9.9	15.0	20.0	25.0%
H	B_n, Normal induction						
1.0	30	50	400	200	100	50	50
4	200	300	800	1 700	1 300	400	300
20	2 800	3 800	1 500	11 000	7 300	4 800	3 600
100	12 100	12 900	2 100	18 900	16 500	14 700	12 000
400	16 300	17 000	2 800	21 500‡	20 500‡	19 400‡	15 900‡
Annealed	950°	950°	950°	920°	900°	917°	917°C
μ_n(max.)	200	172	400	605	405	240	187
B_μ*	5 000	8 600	400	10 000	4 050	6 000	6 000
W†	10 860	8 950	278	10 700	15 150	28 200	36 900
H_c†	12.80	10.20	0.50	4.10	5.70	12.00	15.00

	Alloys containing 0.5% Mn					0.1% Mn + 0.2% Si	
Key	124§	126‖	132	133	134	107	111
Ni =	50.0	54.9	89.9	93.3	99.9%	8.0	10.00%
H	B_n, Normal induction						
0.4	800	300	100	100		100	70
1.0	3 400	2 700	600	300	400	500	200
4.0	9 300	8 700	3 600	3 100	1 500	5 200	2 200
20.0	13 800	13 700	6 700	5 800	4 700	14 400	12 400
100.0	15 500	14 300	8 000	7 200	6 200	19 200	18 500
400.0	16 300	14 800	8 500	7 600	6 800	21 900	21 500
Annealed	931°	931°	931°	931°	931°	900°	900°C
μ_n(max.)	3 570	2 860	1 040	800	500	1 300	640
B_μ*	4 600	4 300	2 400	2 400	2 000	5 200	6 400
W†	2 315	1 177	1 453	2 055	3 640	5 990	11 200
H_c†	0.89	0.68	1.42	1.80	3.20	2.36	4.10

	Alloys containing 0.2% Si							
Key	97	98	100	103	105	108	113	122
Ni =	0.50	1.00	1.96	3.85	7.00	9.52	15.0	30.0
H	B_n, Normal induction							
0.2	200	150	150	100	200			100
0.4	1 400	500	400	300	500	100		200
1.0	10 800	7 600	4 200	2 000	1 300	300	200	400
4.0	15 300	15 200	14 700	13 600	8 100	2 700	1 400	1 000
20.0	16 400	16 600	16 600	16 900	16 000	10 600	7 500	2 100
100.0	18 200	18 400	18 500	18 600	19 200	17 000	16 500	2 600
400.0	21 100	21 400	21 500	21 500	22 000	19 900	20 900	3 100
Annealed	920°	900°	940°	902°	1 064°	920°	960°	950°C
μ_n(max.)	11 000	8 330	6 060	4 500	2 400	556	450	500
B_μ*	10 000	10 000	10 000	9 000	6 000	10 000	4 000	250
W†	1 570		2 420	3 030	3 760	10 150	12 300	169
H_c†	0.52		0.80	1.02	1.30	3.90	5.00	0.40

* $B\mu$ = value of B_n for which $\mu_n = \mu_n$(max.). † Cyclic, $B_{max.} = 10\,000$. ‡ For $H = 300$. § For $H = 0.2$, $B_n = 300$. ‖ For $H = 0.2$, $B_n = 100$.

130 Permalloy. Typical composition: 78.3% Ni, 21.35% Fe, 0.37% Co, 0.22% Mn, 0.10% Cu, 0.04% C, 0.035% S, 0.003% Si, traces of P. Heated 1 hr at 900°C and cooled slowly; reheated to 600°C and cooled on Cu plate at room temperature (4).

For $B_{max.} = 5\,000$, W and H_c are, each, only 1/16 of its value for soft Armco iron. $\mu_n(max.) = 87\,000$ (Fig. 28) is not exceptional (4). Reluctivity (38) is $\mu_n^{-1} = (a + bH)10^{-5}$; if $0 < H < 0.04$, $a = 9.5$, $b = -225$; $0.06 < H < 4$, $a = 0.5$, $b = +9.85$; $4 < H < 22$, $a = 0.3$, $b = +9.1$. For other data, *see* Figs. 28 to 33.

Sb, Antimony irons (71). Alloys were prepared from Swedish iron and "pure antimony" of commerce, free from As and Pb. Bars were cast in iron molds. κ_0 = initial susceptibility ($H = 0$); W = hysteresis loss per cycle, $W = \eta B^e$.

% Sb	κ_0	% Sb	κ_0	η	e	% Sb	κ_0	η	e
26.0	0.000091	38.6	0.0051			51.2	0.330	1.95	1.78
29.8	0.00023	42.7	0.125	1.39	2.17	54.4	0.82	1.06	1.78
33.9	0.00050	45.2	0.167	2.10	1.99	56.8	1.06	1.15	1.70

Si, Silicon irons. *See also* Tables 3, 4, 9, 11, **60** to **69**, Table 7, Figs. 11, 13. The presence of Si in C-irons, with prolonged heating at 975°C, prevents H_c from rising above its value for nearly pure Fe. In ferrosilicons which are as pure and as poor in C as commercially obtainable, H_c for $B_{max.} = 10\,000$ may be as low as 0.4 or 0.5 gauss (23). In certain cases $\mu_{n(max.)}$ exceeds that for pure iron. For anhysteretic magnetization, *see* Table 2 (**65**).

Silicon steel (23). If unannealed, $d_{red.} = 7.874 - 0.0622p$, $p < 4$; $\rho_{20,\,red.} = 9.9 + 12p$, $p < 4$; for $p = 4.45, 5.26, 8.42$, $\rho = 61.26$, 71.86, 93.46, respectively. $4\pi I_{\infty\,red.} = 21\,600 - 480p$.

Si	0	0.075	0.315	0.63	1.03	2.41	3.70	4.45	5.26%
1000α	5.7	5.4	4.2	3.2	2.5	1.3	0.87	0.68	0.52

Admixture	H_c		Admixture		H_c		
% C	Dissolved	Cementite	% C	% Si	Before annealed	Annealed 700°C	Annealed 975°C
0.21	13	2.3	0.21	2.4	1.30	1.19	0.70
0.29	18	2.9	0.29	4.5	1.26	0.65	0.69
0.18	11	2.1	0.18	5.25	1.93	0.70	0.59
0.34	20	3.2	0.34	8.35	6.56	4.60	0.70

Key	60*	60†	61*	61†	63*	63†	67*	67†
H	μ_n, Normal permeability							
0.25	800	1 680	1 000	2 000	3 280	1 200	2 200	800
0.5	1 300	3 000	1 400	2 700	4 200	1 720	3 100	1 240
0.75	2 000	6 930	1 870	6 000	4 540	2 530	3 870	1 970
1.0	2 700	8 450	2 300	7 650	4 650	3 200	4 200	3 000
1.5	3 400	6 930	2 760	7 130	4 490	3 530	4 200	5 670
2.5	3 300	5 290	2 570	5 080	3 870	3 300	3 600	4 570
5	2 300	2 920	2 030	2 820	2 660	2 350	2 430	2 570
10	1 390	1 530	1 330	1 480	1 490	1 360	1 370	1 350
20	760	790	730	770	780	730	730	710
50	330	335	320	330	335	315	315	305
100	176	179	171	174	177	168	170	163
150	122	124	120	121	123	116	119	114
300	66		65		65		62	
500	42		40		40		38	
1 000	22		21		21		20	
2 000	11		11		11		11	
3 000	7.9		7.7		7.6		7.4	
4 000	6.212		6.052		5.94		5.778	
4 500	5.633		5.514		5.39		5.251	
	B, Cyclic induction							
150	18 400	18 600	17 950	18 200	18 400	17 500	17 900	17 070
100	17 560	17 900	17 150	17 430	17 670	16 800	17 000	16 310
50	16 580	16 970	16 100	16 500	16 680	15 780	16 830	15 330
25	15 820	16 300	15 260	15 830	16 010	15 030	14 980	14 710
10	15 100	15 810	13 870	15 320	15 260	14 200	14 260	14 100
5	14 370	15 500	11 620	15 000	14 360	13 220	13 500	13 820
2.5	13 300	15 300	9 900	14 710	12 800	11 350	11 840	13 600
+ 1	11 780	15 100	8 060	14 460	10 160	9 050	9 660	13 330
0	9 850	14 800	5 700	14 080	6 800	6 600	6 000	13 000
− 0.25	9 200	14 500	4 850	13 780	5 400	5 700	4 000	12 820
− 0.5	8 400	13 880	3 700	12 750	+ 3 300	4 300	+ 1 600	12 550
− 0.75	7 350	+ 4 800	+ 2 150	+ 7 700	− 1 500	+ 1 800	− 980	11 800

Continued on p. 398

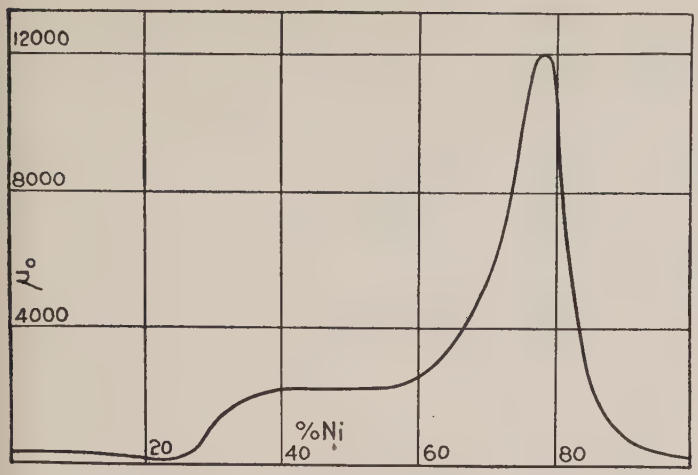

FIG. 27.—Ferronickels (Fe-Ni): Variation of initial permeability (μ_0) with amount of Ni (4).

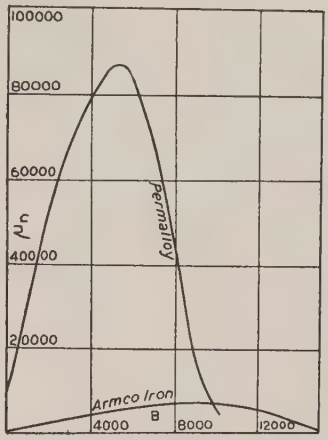

FIG. 28.—Permalloy (**130**): Normal permeability (4); *cf.* Fig. 29.

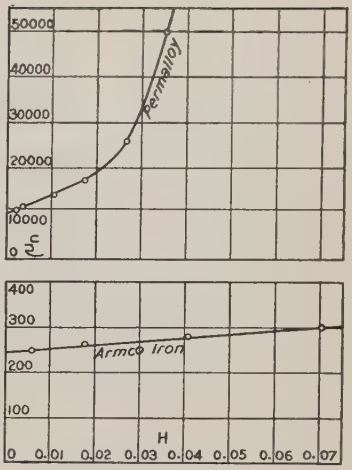

FIG. 29.—Permalloy (**130**): Normal permeability (4); *cf.* Fig. 28.

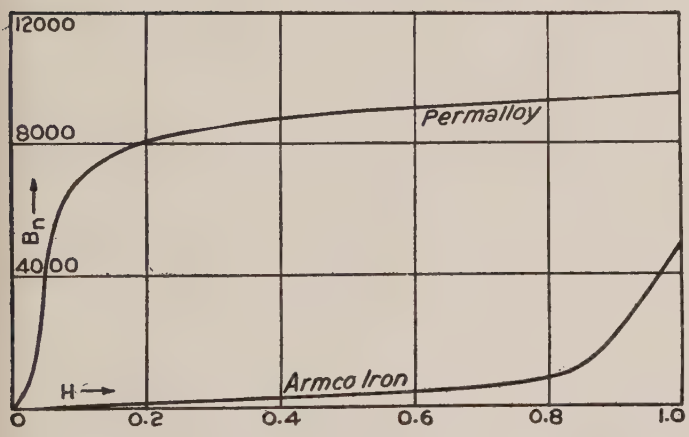

FIG. 30.—Permalloy (**130**): Normal induction (4); *v. also* Figs. 31, 32.

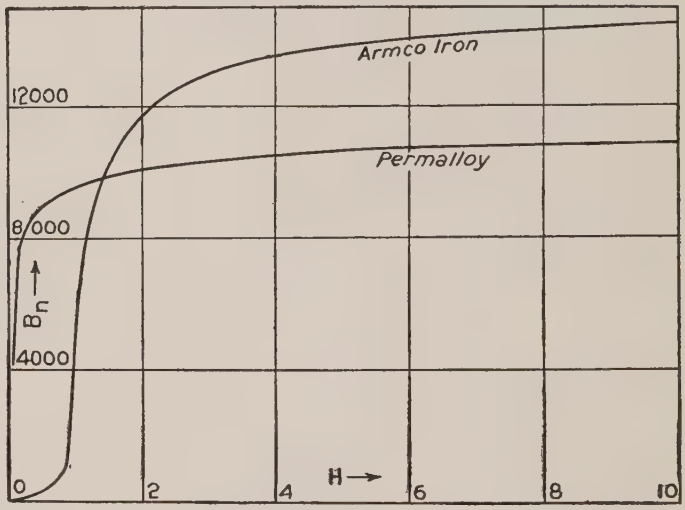

FIG. 31.—Permalloy (**130**): Normal induction (4); *v. also* Figs. 30, 32.

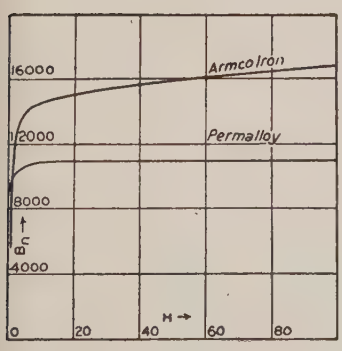

FIG. 32.—Permalloy (**130**): Normal induction (4); *v. also* Figs. 30, 31.

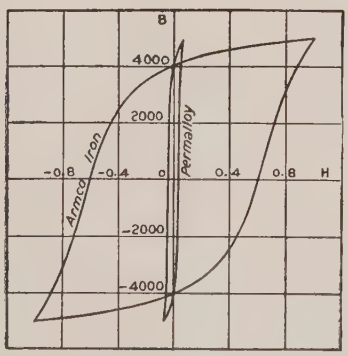

FIG. 33.—Permalloy (**130**): Cyclic induction (4).

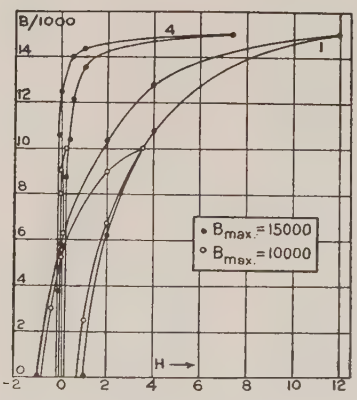

FIG. 36.—Silicon irons: Two specimens of same Si content (92). (1) = commercial silicon steel, 3 to 4 % Si, W = 2160 if $B_{max.}$ = 10 000, W = 4 290 if $B_{max.}$ = 15 000, ρ = 51.15 microhm-cm. (4) = pure, vacuum cast, silicon iron, 3.4 % Si, W = 280 if $B_{max.}$ = 10 000, W = 1 025 if $B_{max.}$ = 15 000, ρ = 48.50 microhm-cm. Both specimens annealed; *cf.* Fig. 38.

TABLE 17.—(*Continued from p. 396*)

Key	60*	60†	61*	61†	63*	63†	67*	67†
				B, Cyclic induction				
− 1.0	+ 6 000	− 6 550	0	− 5 200	− 3 900	− 1 750	− 3 100	+ 2 600
− 1.5	− 900	−10 480	− 3 200	− 9 730	− 6 400	− 4 800	− 5 880	− 8 300
− 2.5	− 7 100	−13 230	− 6 120	−12 400	− 9 620	− 7 980	− 8 800	−11 420
− 5	−11 350	−14 400	−10 140	−14 020	−13 280	−11 570	−12 130	−12 840
− 10	−13 880	−15 130	−13 300	−14 720	−14 900	−13 470	−13 720	−13 520
− 20	−15 200	−15 840	−14 670	−15 420	−15 680	−14 520	−14 570	−14 200
− 50	−16 520	−16 820	−15 920	−16 420	−16 640	−15 700	−15 750	−15 220
−100	−17 550	−17 880	−17 100	−17 420	−17 660	−16 770	−17 000	−16 300
−150	−18 400	−18 600	−17 950	−18 200	−18 400	−17 500	−17 900	−17 070
B_r	9 850	14 800	5 700	14 080	6 800	6 600	6 000	13 000
H_c	1.45	0.775	1.00	0.835	0.67	0.835	0.65	1.06
$\mu_{n(max.)}$	3 470	8 480	2 680	7 700	4 870	3 560	4 450	5 700
μ_0	(200)		238		435		510	
$4\pi I_{\infty obs.}$	20 850		20 270		19 780		19 080	
$4\pi I_{\infty red.}$	21 160		20 580		19 960		19 520	
$1000\eta_{max.}$	1.68	1.22	1.44	1.25	0.79	0.116	0.86	1.41
ρ_{20}	23.24		39.64		51.73		61.26	
$1000\alpha_{red.}$	2.47		1.31		0.87		0.68	
$d_{red.}$	7.815		7.719		7.640		7.597	

Key	64‡	64§	H	64‡	64§	H	64‡	64§
H	μ_n			*B*, Cyclic			*B*, Cyclic	
0.25	4 000	1 200	±65	±15 600	15 450	− 0.5	− 900	+ 3 150
0.5	6 700	2 200	50	15 220	15 060	− 0.75	− 4 780	0
0.75	7 400	3 330	25	14 480	14 230	− 1.0	− 6 700	− 2 250
1.0	7 000	3 600	10	13 770	13 180	− 1.5	− 8 480	− 4 650
1.5	5 790	3 540	5	13 150	11 900	− 2.5	−10 280	− 7 100
2.5	4 160	2 950	2.5	12 260	10 240	− 5	−12 100	− 9 970
5	2 450	2 020	+ 1	10 700	8 360	−10	−13 230	−12 300
10	1 330	1 240	0	7 830	6 130	−20	−14 080	−13 700
20	700	690	− 0.25	+5 600	5 140	−50	−15 220	−15 040
50	305.4	300.8	B_r	7 830	6 130	H_c	0.47	0.75
65	240.0	237.7	$\mu_{n(max.)}$	7 500	3 630			

* Bar; t_a = 800°C. † Sheet, 0.5 mm thick; t_a = 800°C. ‡ Sheet 0.4 mm thick; t_a = 800°C. § Sheet 0.4 mm thick; t_a = 1000°C.

Pure silicon iron (92). Electrolytic Fe, containing 0.006 to 0.01% C, 0.01% Si, was fused *in vacuo* with a ferrosilicon containing 92.23% Si, 8.50% Fe, 0.016% C. Ingots were forged into bars, heat treated, and studied; magnetic properties are improved by annealing; for t_a = 1100 they are a little better than for t_a = 900°C. Data for material annealed at 1100°C are given in Figs. 34 to 38 and the following table; for results of other heat treatments, *see* (92).

% Si	μ_n(max.)	B_μ*	μ_n†	$B_{max.}$ = 10 000			$B_{max.}$ = 15 000			
				W	B_r	H_c	W	B_r	H_c	ρ_{20}
0.001	22 800	8 000	21 300	665	9 300	0.20	1 860	13 300	0.24	9.84
0.001	25 800	9 000	25 600	707	9 300	0.23	1 451	12 700	0.28	9.85
0.01	29 000	9 000	28 670	707	9 600	0.21	1 604	14 300	0.31	9.90
0.040	27 000	10 000	27 000	700	9 440	0.23	1 660	14 480	0.32	10.50
0.064	36 800	9 000	36 300	502	9 500	0.16	1 336	14 300	0.25	10.67
0.068	44 200	9 000	43 500	407	9 480	0.13	1 214	14 200	0.22	10.78
0.091	45 250	9 000	43 500	394	9 500	0.13	929	14 300	0.17	10.96
0.148	66 500	6 500	41 700	286	9 080	0.09	916	12 000	0.16	11.80
0.205	30 200	9 000	29 500	649	9 300	0.20	1 526	14 480	0.27	12 50
0.242	36 500	7 500	33 000	436	9 700	0.13	1 346	14 500	0.21	13.40
0.309	44 800	9 000	43 500	445	9 600	0.13	1 412	14 500	0.24	14.40
0.400	22 500	9 000	22 000	725	9 440	0.21	1 820	14 480	0.32	15.30
0.472	31 150	6 200	25 000	535	9 300	0.16	1 358	14 200	0.21	16.57
0.563	25 000	9 000	25 000	601	9 200	0.20	1 624	14 320	0.28	17.50
0.673	28 000	7 000	24 500	468	9 200	0.13	1 636	13 670	0.23	19.10
0.698	20 350	8 000	19 600	780	9 300	0.25	2 220	14 400	0.40	19.60
0.822	30 800	9 500	30 300	542	9 200	0.18	1 765	14 100	0.35	21.25
1.71	30 150	6 500	24 700	440	8 700	0.12	1 292	12 000	0.22	33.25
1.740	33 000	7 000	26 300	416	9 200	0.13	1 112	12 600	0.19	31.00
2.73	46 800	9 500	46 000	404	9 100	0.13	1 260	13 300	0.23	42.00
3.40	63 300	6 500	46 500	280	9 100	0.08	1 025	12 400	0.15	48.50

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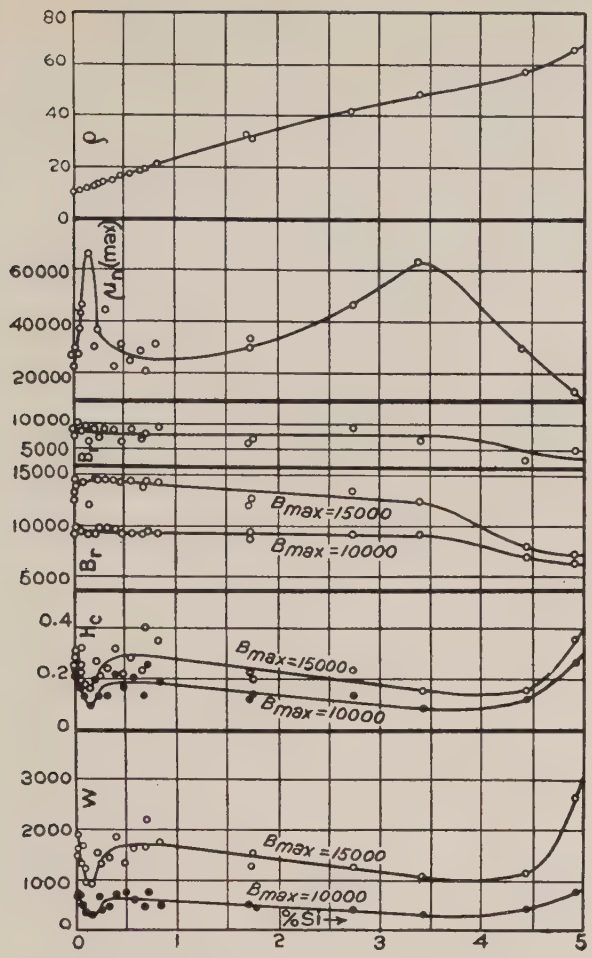

Fig. 34.—Silicon irons: Effect of Si (92).
Unit of ρ = 1 microhm-cm; of other quantities = 1 cgsm unit.

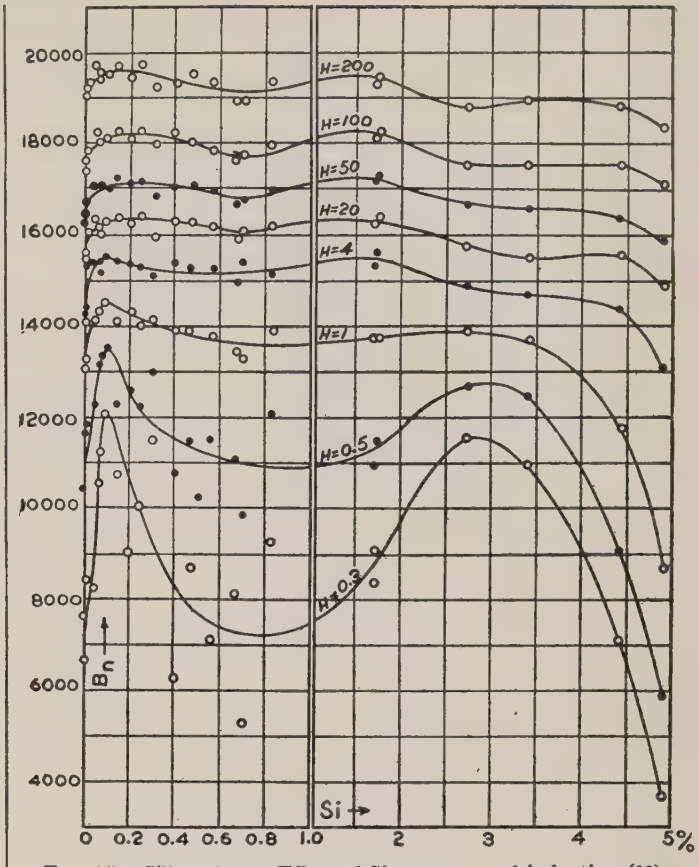

Fig. 35.—Silicon irons: Effect of Si upon normal induction (92).

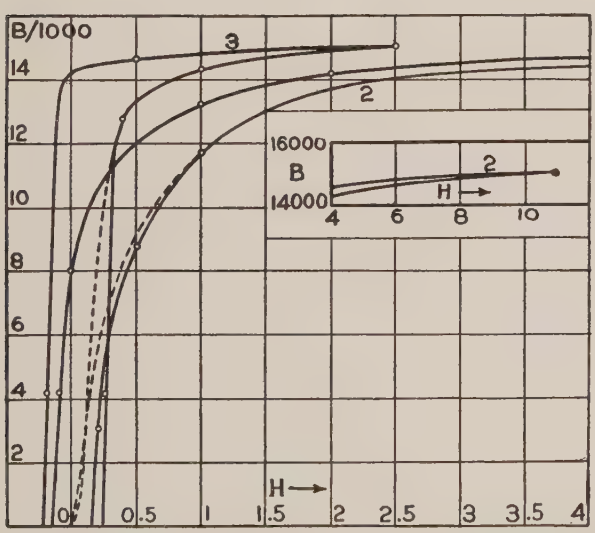

Fig. 37.—Silicon irons: Two pure specimens of different Si content (92).

Both specimens are pure, vacuum cast, silicon irons annealed from 1100°C. (2) contains 4.44 % Si, W = 405 if $B_{max.}$ = 10 000, W = 1171 if $B_{max.}$ = 15 000, ρ = 57.40 microhm-cm. (3) contains 0.048 % Si, W = 407 if $B_{max.}$ = 10 000, W = 1 214.5 if $B_{max.}$ = 15 000, ρ = 10.78 microhm-cm; *cf.* Fig. 38.

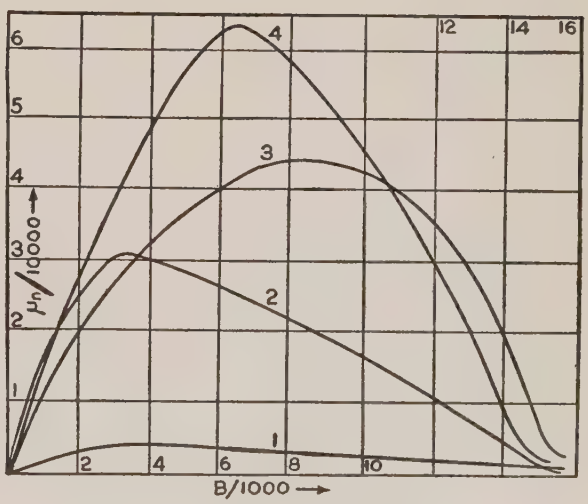

Fig. 38.—Silicon irons: Permeability (92).

Specimen (1) is commercial silicon steel, 3 to 4 % Si, annealed; (2), (3), and (4) are pure, vacuum cast, silicon irons annealed from 1100°C, and contain, respectively, 4.44, 0.048, and 3.4 % Si. Same materials as for Figs. 36, 37, and section on silicon irons in Table 17, p. 396.

TABLE 17.—(*Continued from p. 398*)

% Si	μ_n(max.)	B_μ*	μ_n†	$B_{max.}$ = 10 000			$B_{max.}$ = 15 000			
				W	B_r	H_c	W	B_r	H_c	ρ_{20}
3.55‡	36 000	7 500	29 500	419	8 920	0.13	1 157	12 000	0.21	48.50
4.39‡	25 700	6 000	15 400	591	8 300	0.20	1 819	10 200	0.25	56.10
4.44‡	30 200	3 000	15 900	405	7 000	0.12	1 171	8 000	0.15	57.40
4.92‡	12 200	5 000	7 040	780	6 300	0.26	2 620	7 100	0.35	66.20
0.15§	66 500	6 500		286			916			11.8
3.40§	63 300	6 500		280			1 025			48.5

* Value of B at which $\mu_n = \mu_n$(max.).
† Value for B = 10 000.
‡ These 2 bars were annealed in N; inferior to those annealed *in vacuo*.
§ These are best two alloys obtained.

68, Cast iron ([23]). C = 3.109, Si = 3.270, Mn = 0.560, P = 1.050, S = 0.061%; *see* Tables 4, 9, 11, **68, 69.**

V, Vanadium iron ([43]) **135.** Pure Fe was fused with ferrovanadium; the product contained 3.5% V, 0.22% Mn, 0.60% C of which 0.50% was combined, no Cr, traces of Si. Data refer to 4 states: (1) as cast; (2) annealed from 900 or 950°; (3) quenched at 900 or 950°; and (4) reannealed from 900 or 950°C. The hysteresis loss per cm³ per cycle is $W = \eta B^e_{max.}$.

Cast		Annealed		Quenched		Reannealed	
H	μ_n	H	μ_n	H	μ_n	H	μ_n
2.8	71	2.8	64	2.8	36	2.8	64
4.3	84	4.3	72	5.8	41	5.8	75
5.8	95	7.25	76	8.7	46	7.25	86.5
7.25	120	10.1	104	11.6	46.5	8.7	95
8.7	171	13.0	138	14.5	49	10.1	101.6
10.1	225	14.5	163	17.5	49.1	11.6	106.1
11.1	251	17.5	232	23.5	49.8	14.5	120.7
13.5	348	20.5	273	26.5	50.0	17.5	146.3
14.5	368	23.5	298	29.5	55.5	20.5	163.7
17.5	422	26.5	309	32.6	57.7	23.5	178.9
20.5	424	29.5	304	38.7	69.8	26.5	203.8
23.5	413	44.9	253	41.8	73.0	29.5	210.8
26.5	408	60.1	208	44.9	80.2	38.7	214.5
29.5	387	75.6	174	47.9	83.5	44.9	210.0
44.9	285	91.5	148.6	50.9	90.4	60.1	181.4
60.1	226.3	106.4	131.3	53.9	98.3	75.6	154.9
75.6	186.5	121.7	117.9	57.0	102.8	85.1	142.0
91.5	157.4	140.0	104.6	60.1	109.8	91.5	135.0
121.7	122.4			66.2	116.9	106.4	120.4
				69.5	122.3	121.7	107.5
				75.6	120.0	140.0	95.4
				91.5	113.7		
				106.4	104.1		
				121.7	95.3		
				140.0	85.0		

135 (Cast), Cyclic induction, η = 0.0132; e = 1.6

H	B	H	B	H	B	H	B	H	B
14.5	5 280	29.5	11 400	44.9	12 440	60.1	13 200	91.5	14 100
11.6	5 120	26.5	11 300	41.8	12 300	47.9	12 950	75.6	13 900
10.1	5 010	23.5	11 200	38.7	12 250	41.8	12 800	60.1	13 600
8.7	4 890	20.5	11 000	35.6	12 200	35.6	12 600	44.9	13 200
7.2	4 770	17.5	10 900	32.6	12 100	29.5	12 400	32.6	12 900
5.8	4 650	14.5	10 800	29.5	12 000	23.5	12 220	20.5	12 400
4.3	4 470	11.6	10 600	17.5	11 500	17.5	12 000	14.5	12 100
2.8	4 040	8.7	10 400	14.5	11 400	11.6	11 650	8.7	11 800
+ 1.4	4 140	5.8	10 200	11.6	11 280	5.8	11 200	+ 2.8	11 400
− 1.4	3 810	2.8	9 800	8.7	11 090	+ 2.8	11 000	− 2.8	10 700
− 2.8	3 710	+ 1.4	9 700	5.8	10 750	− 2.8	10 200	− 5.8	9 800
− 4.3	3 330	− 1.4	9 300	+ 2.8	10 500	− 5.8	9 300	− 8.7	7 800
− 5.8	2 780	− 2.8	9 000	− 2.8	9 760	− 8.7	6 700	−10.1	5 700
− 7.2	1 570	− 5.8	8 100	− 5.8	8 700	−10.1	4 300	−11.6	+ 3 000
− 8.7	+ 460	− 7.2	7 500	− 8.7	6 600	−11.6	+ 1 600	−14.5	− 2 900
−10.1	−1 550	− 8.7	6 500	−10.1	4 000	−13.0	− 800	−17.5	− 6 300
−11.6	−2 430	−10.1	3 400	−11.6	+ 800	−14.5	− 3 750	−23.5	− 9 700
−14.5	−5 280	−11.6	+ 400	−13.0	− 1 700	−17.5	− 6 600	−29.5	−11 000
		−13.0	− 2 300	−14.5	− 4 250	−20.5	− 8 580	−44.9	−12 400

TABLE 17.—(*Continued*)

H	*B*	*H*	*B*	*H*	*B*	*H*	*B*	*H*	*B*
		−14.5	− 4 500	−17.5	− 6 800	−23.5	− 9 700	−60.1	−13 000
		−16.0	− 5 000	−20.5	− 8 600	−29.5	−11 100	−75.6	−13 600
		−17.5	− 7 400	−26.5	−10 400	−44.9	−12 400	−91.5	−14 100
		−20.5	− 9 100	−38.6	−11 700	−60.1	−13 200		
		−23.5	−10 300	−44.9	−12 440				
		−26.5	−10 700						
		−29.5	−11 400						
B_r	4 000	9 500		10 300		10 800		11 200	
H_c	9.3	11.6		12.0		12.5		13.0	
W	12 100	40 930		46 950		51 870		58 870	

135 (Annealed), Cyclic induction, $\eta = 0.0164$; $e = 1.6$

H	*B*	*H*	*B*	*H*	*B*	*H*	*B*	*H*	*B*
15.1	2 690	29.5	8 970	44.9	11 250	60.1	12 350	91.5	13 600
10.7	2 495	26.5	8 850	38.7	11 060	50.9	12 100	78.7	13 380
9.0	2 330	23.5	8 625	32.6	10 830	41.8	11 840	69.5	13 220
6.0	2 070	20.5	8 540	29.5	10 720	35.6	11 650	60.1	12 990
4.5	1 920	17.5	8 470	23.5	10 430	29.5	11 390	47.9	12 630
3.0	1 820	14.5	8 180	17.5	10 100	23.5	11 060	38.7	12 310
+ 1.5	1 650	11.6	7 890	14.5	9 930	17.5	10 760	29.5	11 940
− 1.5	1 330	8.7	7 770	11.6	9 725	11.6	10 320	17.5	11 250
− 3.0	1 120	5.8	7 500	8.7	9 460	5.8	9 770	8.7	10 550
− 4.5	856	2.8	7 170	5.8	9 190	+ 2.8	9 420	+ 2.8	9 690
− 6.0	540	+ 1.4	6 990	+ 2.8	8 870	− 2.8	8 580	− 2.8	8 810
− 7.5	+ 150	− 1.4	6 610	− 2.8	8 080	− 5.8	7 650	− 5.8	8 180
− 9.0	− 330	− 2.8	6 350	− 5.8	7 140	− 8.7	6 740	− 8.7	7 300
−10.0	− 630	− 5.8	5 740	− 8.7	6 150	−10.1	6 250	−11.6	5 910
−10.6	− 780	− 8.7	4 370	−11.6	4 780	−11.6	5 400	−13.0	5 100
−11.1	−1 100	−11.6	+3 220	−14.5	+ 2 450	−13.0	4 420	−14.5	4 150
−12.0	−1 250	−14.5	− 140	−17.5	− 1 550	−14.5	3 080	−17.5	+ 200
−15.1	−2 690	−17.5	−3 880	−20.5	− 4 610	−16.0	+ 1 530	−20.5	− 3 000
		−20.5	−6 720	−26.5	− 7 470	−17.5	− 90	−22.0	− 4 700
		−23.5	−7 570	−29.5	− 9 060	−20.5	− 4 120	−23.5	− 5 700
		−26.5	−8 220	−35.6	−10 350	−29.5	− 9 060	−26.5	− 7 900
		−29.5	−8 970	−44.9	−11 250	−44.9	−11 260	−29.5	− 8 700
						−60.1	−12 350	−32.6	− 9 300
								−44.9	−11 300
								−60.1	−12 900
								−75.6	−13 260
								−91.5	−13 600
B_r	1 400	6 800		8 600		9 000		9 200	
H_c	8.1	14.5		16.7		17.3		17.8	
W	4 973	35 160		50 160		57 890		67 080	

135 (Quenched), Cyclic induction, $\eta = 0.0096$; $e = 1.7$

H	*B*	*H*	*B*	*H*	*B*	*H*	*B*	*H*	*B*
14.5	672	29.5	1 600	44.9	3 530	60.1	6 500	91.5	10 400
8.7	454	20.5	1 230	29.5	2 950	53.9	6 340	75.6	10 060
5.8	237	14.5	1 000	23.5	2 700	44.9	6 190	60.1	9 720
2.8	212	11.6	840	17.5	2 440	29.5	5 500	44.9	9 465
+ 1.4	165	8.7	730	11.6	2 130	14.5	4 820	29.5	8 880
− 1.4	+ 56	5.8	600	8.7	1 850	5.8	4 400	17.5	8 430
− 2.8	− 38	+ 2.8	430	+ 2.8	1 680	+ 2.8	4 250	11.6	8 200
− 5.8	−217	− 2.8	200	− 2.8	1 380	− 2.8	3 930	5.8	7 920
− 8.7	−381	− 5.8	+ 40	− 5.8	1 180	− 5.8	3 580	+ 4.3	7 870
−11.6	−520	− 8.7	− 225	− 8.7	890	− 8.7	3 220	− 4.3	7 400
−14.5	−672	−11.6	− 440	−11.6	680	−11.6	2 910	− 5.8	7 000
		−14.5	− 590	−14.5	440	−14.5	2 660	−11.6	6 500
		−17.5	− 810	−17.5	+ 180	−17.5	2 400	−17.5	6 050
		−20.5	−1 020	−20.5	− 440	−20.5	2 190	−23.5	5 420
		−23.5	−1 210	−23.5	− 750	−23.5	1 775	−29.5	4 630
		−29.5	−1 600	−26.5	−1 130	−26.5	1 400	−35.6	3 470
				−29.5	−1 450	−29.5	830	−38.7	2 590

TABLE 17.—(*Continued*)

H	*B*	*H*	*B*	*H*	*B*	*H*	*B*	*H*	*B*
				−35.6	−2 450	−32.6	+ 140	−41.8	+ 1 580
				−38.7	−2 830	−35.6	− 560	−44.9	− 200
				−44.9	−3 530	−41.8	−2 380	−50.9	− 3 210
						−44.9	−3 330	−53.9	− 4 720
						−47.9	−4 270	−60.1	− 7 370
						−53.9	−5 400	−75.6	− 9 600
						−60.1	−6 500	−91.5	−10 400
B_r	110	315		1 500		4 000		7 600	
H_c	2.5	6.5		17.5		33.5		44.5	
W	231	1 464		13 610		49 490		114 100	

135 (Reannealed), Cyclic induction, $\eta = 0.02$; $e = 1.6$

H	*B*	*H*	*B*	*H*	*B*	*H*	*B*	*H*	*B*
14.5	1 750	29.5	6 220	44.9	9 425	60.1	10 900	91.5	12 350
10.1	1 470	26.5	6 080	38.7	9 295	53.9	10 720	75.6	12 020
8.7	1 370	23.5	5 920	32.6	8 930	44.9	10 415	60.1	11 710
5.8	1 170	20.5	5 710	29.5	8 875	38.7	10 185	44.9	11 130
2.8	940	17.5	5 520	26.5	8 745	32.6	9 920	35.6	10 780
+ 1.4	785	14.5	5 350	23.5	8 475	26.5	9 620	29.5	10 500
− 1.4	595	11.6	5 100	20.5	8 290	20.5	9 300	23.5	10 280
− 2.8	+ 380	8.7	4 900	17.5	8 000	14.5	8 940	17.5	9 820
− 5.8	− 70	5.8	4 620	14.5	7 900	8.7	8 530	11.6	9 430
− 8.7	− 735	2.8	4 300	11.6	7 675	+ 2.8	7 600	5.8	8 450
−10.1	−1 010	+ 1.4	4 170	8.7	7 465	− 2.8	6 750	+ 2.8	8 140
−11.6	−1 280	− 1.4	3 830	5.8	7 215	− 8.7	5 350	− 2.8	7 350
−14.5	−1 750	− 2.8	3 600	+ 2.8	6 915	−14.5	3 580	− 5.8	6 940
		− 5.8	2 980	− 2.8	5 885	−17.5	2 360	− 8.7	6 070
		− 8.7	1 930	− 5.8	5 275	−20.5	+ 1 020	−11.6	5 270
		−11.6	+ 190	− 8.7	4 425	−23.5	− 1 180	−13.0	4 950
		−14.5	− 180	−11.6	3 500	−29.5	− 5 700	−14.5	4 360
		−17.5	−1 650	−14.5	2 530	−32.6	− 7 400	−17.5	3 200
		−20.5	−2 990	−17.5	+1 415	−35.6	− 8 315	−20.5	+ 1 740
		−23.5	−4 280	−20.5	− 275	−41.8	− 9 330	−23.5	− 90
		−26.5	−5 130	−23.5	−2 655	−47.9	−10 330	−26.5	− 2 470
		−29.5	−6 220	−26.5	−4 665	−60.1	−10 900	−29.5	− 4 850
				−29.5	−5 945			−32.6	− 6 680
				−35.6	−8 145			−35.6	− 7 960
				−38.7	−8 500			−44.9	− 9 610
				−44.9	−9 425			−60.1	−11 170
								−75.6	−11 990
								−91.5	−12 350
B_r	650	3 950		6 500		7 100		7 700	
H_c	5.5	14.0		20.0		22.0		23.5	
W	1 919	20 810		46 670		57 750		67 740	

W, Tungsten iron. *See* p. 385 and Tables 12, 13, 15, 16 (**84, 136** to **144**).

Cobalt

TABLE 18.—MAGNETIC PROPERTIES

For properties in very intense fields, *see* Table 4. Composition and heat treatment of specimens are not stated. Annealed Co is magnetically much harder than unannealed cast Co. Above 700°C, Co is very hard and it is not certain that saturation has been attained at these temperatures. For ferrocobalts, *see* Table 17 (Co); for nickel-cobalts, *see* Table 20 (Co).

146*I* ([53]) (σ_∞ extrapolated from data for $H = 13\,500$)

t	σ_∞	*t*	σ_∞	*t*	σ_∞	*t*	σ_∞
17	165.5	1069	71.3	+ 17	165.5	641	140.6
510	149.2	1016	88.2	−188	167.9	437	152.7
693	136.9	804	125.3	+ 17	165.5	362	156.1
844	120.5	918	109.1	1149	17.9	205	160.9
971	99.4	614	142.9	1133	32.1	324	156.9
1090	62.5	470	151.0	1144	20.6		
1067	72.2	748	131.8	16	165.5		

TABLE 18.—(*Continued*)

146*II*$_c$ (34)				**146***II*$_a$, Annealed at 1000° (34)			
20.0°C		−186°C		18.6°C		−186°C	
H	I_n	H	I_n	H	I_n	H	I_n
5.1	72	3.90	28	4.37	6	7.80	9
10.7	170	10.57	122	13.53	26	16.23	20
13.9	247	22.65	277	25.25	67	39.0	64
22.8	371	39.3	427	36.59	115	57.8	102
35.7	497	74.7	608	52.5	171	80.0	148
54.5	628	101.9	690	86.7	257	119.6	221
85.9	749	206.6	848	122.3	320	167.4	282
147.7	865	281.1	911	221.8	433	248.4	358
244.3	953	357	956	354	532	347	426
392	1027	449	999	445	583	496	504
467	1047	570	1038	527	613	561	543
610	1088	668	1063	699	687	702	589

146*III*$_c$, Fused in arc, and cast (66)

22°C		414°C		698°C		874°C		1065°C	
H	σ_n	H	σ_n	H	σ_n	H	σ_n	H	σ_n
725	102.4	460	119.2	140	87.5	215	83.4	1165	21.4
1955	139.6	2055	145.8	855	124.1	1300	97.9	2400	26.8
2985	149.1	3135	146.3	1620	124.3	2015	97.9	3060	30.0
3450	153.2	3930	146.4	2115	125.2	2510	98.7	3570	29.7
3955	154.6	4515	146.4	2400	124.9	3915	97.9	4010	29.4
4270	155.2								

Nickel

TABLE 19.—MAGNETIC PROPERTIES

For properties in very weak and in very intense fields, and for variation with temperature in weak fields, *see* Tables 3, 4 (**148, 150**). For impurities, *see* Table 1; *cf.* Figs. 41, 42, 43.

Key	Remarks
146.1	Heraeus. Fused in vacuum. Composition: 99.91% Ni, 0.01% Fe, 0.03% Cu, 0.05% nonmagnetic impurities. Data are corrected for effect of the impurities. At H = 18 550, $\sigma_{17°C}$ = 54.59; from an experimental study of the laws of approach to absolute saturation as H and T are varied, and by an extrapolation from H = 18 550 and T = 100°K to $H = \infty$ and T = 0°K, it was found that σ_∞ = 57.53; hence $\sigma_\infty \times$ atomic weight = 3 376.4 = 3 × 1 125.4; that is, the magnetic moment of the Weiss magneton is 1125.4, *cf.* **1.1,** Table 6, p. 378, *also* p. 345 (80).
147	Very pure. Fused in H in electric furnace; heated to 650°C, cooled slowly to 350°C, then brought to temperature at which magnetization was measured. In general, data are accurate to 0.1 or 0.2%, but do not represent the properties of any other specimen, even though pure, more closely than 1 or 2%. If 480°C < t < 880°C, $\sigma = 0.00552H/(t - 376)$ (39). At 18°C, σ_∞ = 54.5 (73), $d\sigma_\infty/dt = 0.00053\sigma_\infty$ (81). For H = 18 000, $\sigma_{20.3°K} = 1.051\sigma_{19.5°C}$, correction being made for thermal expansion (83).
149	Ni = 99.15%; μ_n(max.) = 1 120; I_∞ = 509.
151	Contains 1.5% Co; annealed; variation of I'_r with t determined as for specimen **17***II* in Table 5.
153	Composition not stated; **153***III*$_s$ is magnetically soft; **153***III*$_h$ is very hard.

147 σ, Specific magnetization (81); *see also* Fig. 39

t \ H	1 000	2 000	4 000	8 000	12 000	18 000	t	σ_s
20.0	53.70	54.09	54.43	54.55	54.63	54.73	18.4	54.5
53.8				53.48	53.53	53.63	53.8	53.4
79.3				52.63	52.68	52.76	79.3	52.4
104.0				51.55	51.63	51.06	104.0	51.4
127.9				50.44	50.51	50.62	127.9	50.2
151.0				49.09	49.17	49.30	151.0	49.0
173.3				47.74	47.83	47.97	173.3	47.5
184.3				47.02	47.07	47.23		

TABLE 19.—(*Continued*)

t \ H	1 000	2 000	4 000	8 000	12 000	18 000	t	σ_s
195.1			45.94	46.13	46.25	46.34	195.1	45.9
205.7				45.25	45.38	45.56		
216.3				44.28	44.40	44.57	216.3	44.0
226.7				43.26	43.39	43.60		
237.1				42.17	42.32	42.53	237.3	41.9
247.3				41.07	41.19	41.42		
257.0				39.81	39.96	40.14	257.0	39.5
267.5				38.43	38.62	38.90		
277.5	36.30	36.50	36.74	36.99	37.21	37.51	277.5	36.6
281.5				36.48	36.61	36.94		
285.4				35.71	35.93	36.27		
289.3				35.06	35.28	35.64		
293.2				34.35	34.59	34.94		
297.1				33.61	33.86	34.28		
301.0		32.28	32.54	32.88	33.15	33.52	301.0	32.3
304.9				32.06	32.36	32.78		
308.8			30.83	31.24	31.58	32.00		
312.7			29.94	30.37	30.71	31.14		
316.5	28.30	28.65	29.00	29.46	29.87	30.26	316.5	28.7
320.3			27.95	28.44	28.82	29.33		
324.2			26.85	27.36	28.28	28.35		
328.0		25.31	25.70	26.28	26.74	27.35		
331.8		24.00	24.39	25.04	25.56	26.28		
335.6	22.08	22.40	22.91	23.66	24.27	25.04	333.7	23.1
339.4	20.42	20.78	21.36	22.21	22.86	23.75		
343.1	18.36	18.85	19.55	20.60	21.39	22.38	341.2	19.8
346.9	16.01	16.62	17.53	18.83	19.81	20.97	346.9	16.4
350.7	12.83	13.82	15.12	16.75	17.93	19.37		
354.4	8.36	10.19	12.22	14.46	15.99	17.66	352.5	10.7
358.1	3.68	6.03	8.83	11.95	13.80	15.77		
361.8	1.78	3.41	5.98	9.41	11.61	13.85		
365.4		2.13	4.13	7.30	9.56	12.06		
369.1		1.51	2.97	5.58	7.72	10.25		
372.8		1.15	2.29	4.43	6.35	8.75		
376.5		0.91	1.82	3.60	5.24	7.39		
380.1		0.75	1.49	2.97	4.38	6.33		
387.5			1.11	2.18	3.25	4.80		
394.8				1.71	2.54	3.79		
405.7			0.64		1.88	2.83		

149 (23)					**153*I*** (20)	
H	B_n	μ_n	H	B*	I	μ
0.25	100	400	150	6 400	0.0	11.2
0.5	230	460	100	6 220	76.8	11.3
0.75	480	530	50	5 930	115	11.0
1.0	650	650	25	5 580	144	10.9
1.5	1 350	900	5	4 680	172	10.5
2.5	2 800	1 120	2.5	4 360	216	9.84
5	4 330	865	+ 1	3 900	249	9.01
10	4 940	495	0	3 340	252	8.81
20	5 400	270	− 0.5	2 800	273	8.42
50	5 850	117	− 0.75	2 460	285	7.90
100	6 200	62	− 1.0	2 000	298	7.43
150	6 400	43	− 1.5	+ 550	314	6.74
300	6 700	22	− 2.5	−2 500	317	6.78
500	6 910	14	− 5	−4 320	329	6.17
1 000	7 370	7.4	− 10	−4 940		
2 000	8 400	4.2	− 20	−5 400		
3 000	9 380	3.1	− 50	−5 850		
4 000	10 400	2.6	−100	−6 200		
			−150	−6 400		

* Cyclic; $H_c = 1.62$, $I_\infty = 509$, $\mu_{max.} = 1120$.

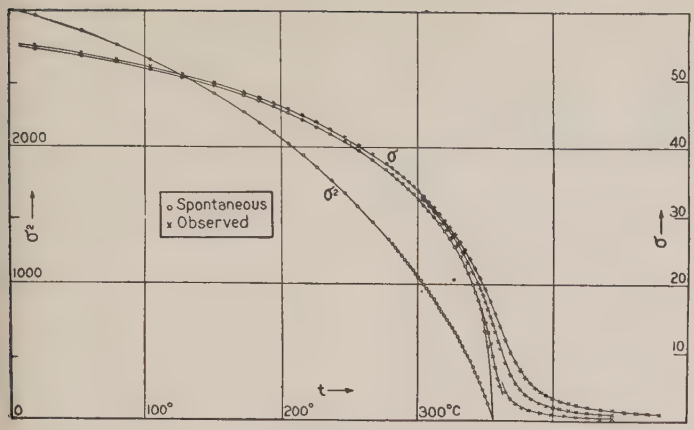

FIG. 39.—Nickel: Magnetization at various temperatures (81). Pure Ni (147) from Merck.

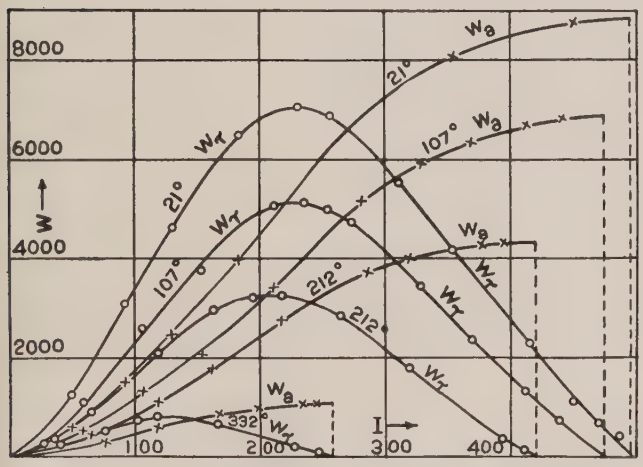

FIG. 40.—Nickel: Alternating (W_a) and rotating (W_T) hysteretic loss (48).

Key number **153**, Table 1. Centigrade temperatures.

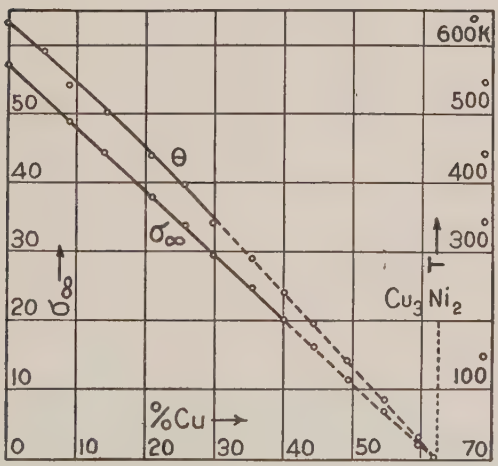

FIG. 42.—Nickel-copper (Ni-Cu) alloys: Magnetization at saturation, and Curie point (1).

Material same as in Table 20. T = absolute centigrade temperature; σ_∞ = value at $T = 0$, corrected for dilatation; Θ is for $H = 0$.

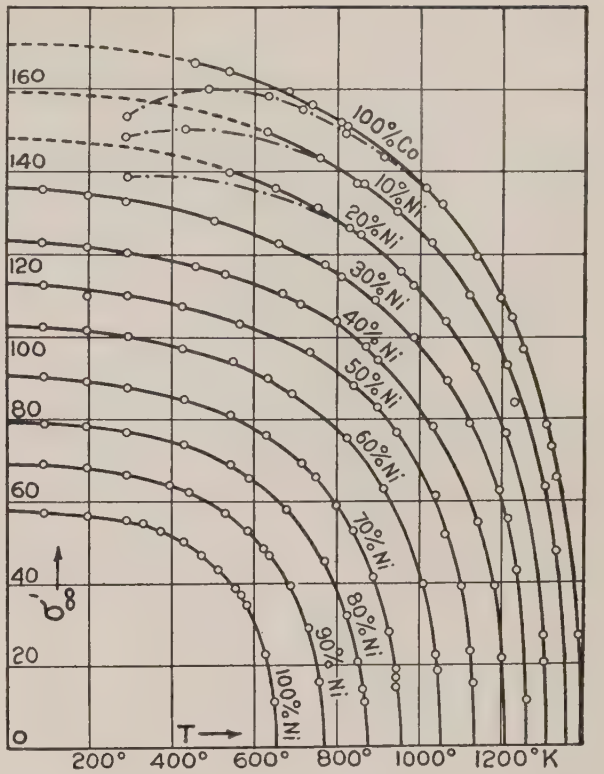

FIG. 41.—Nickel-cobalt (Ni-Co) alloys: Magnetization at saturation (7).

Material same as in Table 20. T = absolute centigrade temperature; broken lines represent σ for $H = 10\,000$.

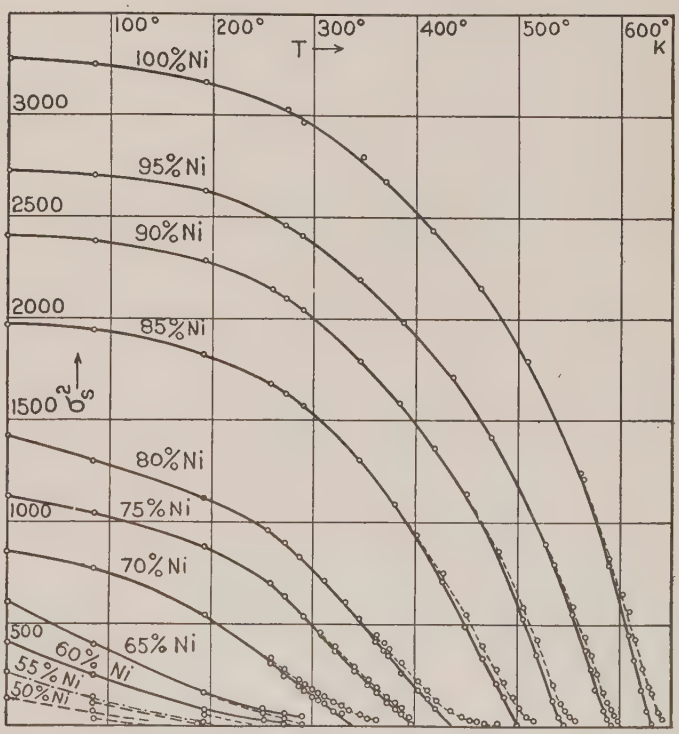

FIG. 43.—Nickel-copper (Ni-Cu) alloys: Spontaneous magnetization (1).

Material same as in Table 20. T = absolute centigrade temperature. Broken lines represent observations at $H = 10\,000$.

TABLE 19.—(*Continued*)

153*III*$_s$ (48); *see also* Fig. 40

H	I	W_τ	W_a	H	I	W_τ	W_a	H	I	W_τ	W_a
21°C				109°C				212°C			
21	49	1 240	590	12	35	360	63	11	28	280	120
37	91	3 090	1 530	21	58	1 110	500	21	65	891	430
49	129	4 600	2 450	37	105	2 570	1 320	37	118	2 090	1 100
68	183	6 460	3 950	49	153	3 760	2 100	49	161	2 940	1 750
88	230	7 010		68	211	5 030	3 420	60	194	3 180	
100	255	6 820	6 200	78	234	5 100	4 230	68	217	3 260	2 730
130	310	5 510		86	254	4 980		88	263	2 800	
158	353	4 180	8 040	94	273	4 940		100	285		3 720
223	415	2 280	8 580	100	281		5 160	158	348	1 490	4 120
319	449	1 200	8 760	126	328	3 430	5 910	319	393	310	4 320
449	470	690	8 820	158	368	2 370	6 340	449	401		4 270
710	487	380	8 630	223	411	1 310	6 660				
				319	439	730	6 800				

322°C				**153*III*$_h$** (48)				**153*I*** (18)	
12	41	230	120	t	W_τ*	W_a*	W_a/W_τ	t	H_c
21	76	510	280	18	12 200	15 500	1.27	−185	29.0
27	103	710		100	9 700	12 700	1.31	− 79	27.5
32	117	800	610	150	8 000	10 700	1.33	+ 15	25.5
49	166	640	830	200	6 310	8 400	1.33	123	21.2
68	195	350	940	250	4 500	6 000	1.33	207	15.7
94	225	210		300	2 580	3 440	1.33	286	9.19
158	233		1 070	350	545	747	1.37	339	3.92
319	245	40	1 060	368	0	0			
449	247		1 060						

151 (49)

t	191	220	250	270	305	361.2°C
I'_τ/I_τ	86.2	81.5	75.0	71.0	58.7	0%

* Maximum loss: Mean of values obtained when heating and when cooling.

Alloys of Nickel

TABLE 20.—NICKEL ALLOYS

Co, Cobalt alloys of Ni (7). Ni and pure Co were fused in electric resistance furnace, in magnesia crucible, current of N. The Ni used contained 98.1% Ni, 1.9% Co, 0.05% Fe. Alloys for which Ni ≤ 20% are too hard magnetically to become saturated, at low temperatures, at H = 10 000. H = 10 000 gauss; t = 19°C; Θ = Curie point (centigrade) for H = 0; *see also* Fig. 41.

Co	d	σ	Θ	Co	d	σ	Θ
0	8.79	55.2	382	60.4	8.72	120.3	934
9.8	8.80	66.8	497	69.8	8.77	132.6	988
18.6	8.87	77.1	601	79.5	8.75	138.7	1037
30.4	8.72	87.7	685	89.3	8.87	148.5	1085
40(?)	8.89	100.0	780	100.0	8.92	153.6	1121
49.3	8.79	110.0	860				

Cu, Copper alloys of Ni (1). In N, pure Cu was fused with nickel containing 99.89% Ni, 0.004% Cu, 0.053% Fe, 0.043%C, 0.008% SiO_2, traces of S. In table, σ_∞ has been corrected for dilatation, and refers to absolute zero. Θ corresponds to H = 0; it is temperature at which spontaneous magnetization = 0; *see also* Figs. 42, 43.

Cu, %	d	σ_∞	Θ, °C	Cu, %	d	σ_∞	Θ, °C
0	8.790	57.2	358	20.5	8.95	37.7	164
5.3	8.787	52.2	318	25.6	8.96	33.9	126
9.1	8.86	49.0	272	29.7	8.99	29.2	67
14.1	8.94	44.4	229	35.5	8.91	24.5	+16

TABLE 20.—(*Continued*)

Cu, %	d	σ_∞	Θ, °C	Cu, %	d	σ_∞	Θ, °C
40.0	8.90	20.0	− 33*	54.1	8.93	6.8*	−188*
44.3	8.85	16.2*	− 79*	59.4	8.93	2.0*	−245*
49.2	8.96	11.4*	−133*	61.8†		0*	−273*

* Extrapolated value. † Corresponds to Cu_3Ni_2.

Fe, For ferronickels, nickel steel, *see* Table 17 (Ni).

Mn, Nickel manganese alloys (21). The metals, protected from all contact with C, were fused under a layer of fused $BaCl_2$. Annealed at 900°C. Unforged castings and specimens quenched at 900°C are, in general, less magnetic than those annealed.

H =	5	10	15	20	40	60	80	100	150	200
% Mn	I_n, Intensity of magnetization; 16°C									
5	20	48	77	97	158	195	224	248	292	316
10	30	75	109	130	212	258	287	308	344	368
15	68	115	148	167	214	240	256	268	288	304
20	20	32	41	47	64	76	85	91	102	110
25	6	12	18	28	58	80	96	109	131	147
30	2	4	7	11	30	48	67	81	112	135
% Mn	I_n, Intensity of magnetization; −190°C									
5	16	40	66	89	155	203	236	264	317	350
10	26	60	97	129	224	280	318	353	404	434
15	42	100	146	176	262	316	344	368	410	438
20	30	70	99	123	181	216	236	250	276	296
25	10	24	38	51	94	130	156	180	217	247
30	3	6	10	14	35	54	72	89	123	152

Manganese Alloys and Compounds

TABLE 21.—FERROMAGNETIC MANGANESE ALLOYS AND COMPOUNDS

For composition of alloys denoted by key numbers, *see* Table 1

As, Two ferromagnetic alloys ([28], [70]); MnAs, Θ = 40 to 45°C, and Mn_2As.

B, One ferromagnetic alloy ([6]); MnB, Θ = 260°C; H_c = 30.9.

H	90.4	181	271	362	542	786
I_n	32.5	54.6	70.7	81.5	110.1	146.1

Bi, One ferromagnetic alloy ([28], [70]); MnBi, Θ = 360 to 380°C.

C, One ferromagnetic alloy ([28], [70]); Mn_3C, no data.

Cu, Cupromanganese is not ferromagnetic, but certain of the three-component alloys containing Al or Sn are.

1. Copper, Manganese, Aluminium (Heusler) alloys ([29]) contain from 5 to 25% Al, Mn > 7%; alloys containing over 30% Mn have not been studied. Of these alloys those of the composition $\chi AlCu_3 + (1 - \chi)AlMn_3$ are the most magnetic (they contain about 13% Al) and, for H = 150, the maximum value of I (about 430) corresponds to χ = 0.6684, or 12.89% Al, 26.12% Mn, 60.98% Cu (*see* Fig. 45). It is understood that each alloy is given the thermal treatment which is most appropriate to itself, *see* Figs. 44, 45, 46. **156** is a typical Heusler alloy.

156t_q = 600°C, drawn at 209°C for τ_d hr

H	2.5	5	10	25	50	100	200	500	700	1000
τ_d	I_n, Normal intensity of magnetization ([67]); *see* Fig. 46									
0	0.04	0.09	0.18	0.45	0.90	1.75	3.11	6.02	7.60	9.73
1	1.34	2.70	5.07	8.78	12	15.9	20.6	26.2	28.0	30.6
2	2.45	5.01	9.37	16.5	22.6	29.0	36.0	44.1	47.7	53.2
3	4.00	8.52	16.2	27.3	35.7	44.1	52.1	61.6	65.5	69.4
4	4.71	11.1	23.1	38.1	48.1	57.3	65.9	75.6	78.6	81.6
5	4.37	11.3	31.1	50.2	61.0	70.8	79.5	88.8	92.1	94.5
6	3.11	9.40	31.1	50.5	62.0	72.5	81.5	91.6	94.7	97.2
7	3.18	9.71	29.0	47.0	59.0	69.8	79.5	90.2	93.4	96.7
8	3.00	7.61	24.7	65.7	70.4	92.1	102.2	113.8	116.4	119.1
9	3.25	8.30	26.5	52.6	64.4	75.5	85.6	96.7	99.7	103.1
10	2.88	7.31	23.5	48.4	61.5	72.7	83.3	95.0	98.6	102.0
12¾	2.10	5.65	21.1	49.3	63.5	75.7	87.6	100.0	103.7	107.5
15	2.05	5.43	16.9	46.2	61.6	75.1	87.6	100.9	104.9	109.4
20	1.80	4.05	10.7	37.3	55.0	71.5	86.7	103.5	108.3	112.7
25	1.15	2.70	6.72	27.3	52.5	68.2	85.2	107.2	113.1	119.1
35	0.88	1.96	4.23	14.9	32.6	53.9	79.0	110.1	119.7	127.3
50	0.61	1.26	2.65	7.88	21.0	44.5	75.3	116.6	128.4	137.8
75	0.42	0.85	1.75	4.55	9.46	20.1	43.4	100.4	116.9	130.1
2100	0.38	0.76	1.52	3.82	7.73	17.0	41.6	118.2	139.0	156.3

H	**155** ([3])		**159** ([3])		Cyclic	**155** ([3])	**159** ([3])	**155**	**159**
	B_n	μ_n	B_n	μ_n	H	B	B	Malleable	Not malleable
2.5	120	48	300	120	150	2250	4250	Cu, 75.6%	61.5%
5	400	80	800	160	100	1980	4110	Mn, 14.25	23.5
7.5	580	77	1600	210	50	1560	3830	Al, 10.15	15.0
10	720	72	2320	230	25	1220	3550	Pb	0.1
20	1070	54	3250	160	+ 5	740	2900		
50	1540	31	3800	76	0	480	2550	B_r, 480	2550
75	1780	24	3980	53	− 0.5	440	2490	H_c, 3.75	7.3
100	1970	20	4110	41	− 1.0	410	2420	μ_n(max.) = 80	236
150	2250	15	4250	28	− 1.5	370	2350	$4\pi I_{\infty obs.}$ = 2790	
300	2800	9.3			− 2.5	+ 250	2190	ρ_{20} = 40.90	
500	3120	6.2			− 5	− 240	+1480		
1000	3670	3.7			− 10	− 670	−1780		
2000	4710	2.4			− 20	−1040	−3210		
3000	5750	1.9			− 50	−1540	−3800		
4000	6780	1.7			− 75	−1780	−3980		
5000	7790	1.6			−100	−1970	−4110		
6000	8790	1.5			−150	−2250	−4250		

TABLE 21.—(*Continued*)

2. Copper, manganese, tin alloys (60). A 98.5% Mn, containing in decreasing amounts Si, Fe, and Al, was alloyed with very pure Cu and Sn; the alloys were drawn for a short time at a temperature below 200°C. There are 2 series of ferromagnetic alloys, separated by the alloy of 30% Sn.

H =		20	50	100	200	300	I_r	H_c	H =	20	50	100	200	300	I_r	H_c
Key	t	I_n							Key	I_n						
162	−190	21	42	67	93	108	31	27	**163**	30	62	96	127	144	26	12
	+ 15	18	36	55	72	80	21	22		28	55	77	96	105	16	10
	75	15	30	46	60	67	18	21		24	46	63	76	84	14	9
Θ = 275°C	125	11	26	37	46	50	13	20	Θ = 270°C	20	37	48	58	61	10	8
	180	8	19	26	34	36	8	18		11	19	27	31	33	5	7
	230	2	3	4	5	5	1	9		4	7	10	12	13	2	5
164	−190	27	59	102	162	195	23	16	**166**	22	54	96	160	209	11	10
	+ 15	24	52	82	117	129	18	14		22	54	96	160	209	11	9
	75	18	36	59	82	89	13	13		22	52	92	153	201	11	9
Θ = 255°C	125	12	23	35	49	54	9	12	Θ = 225°C	21	50	88	142	184	10	8
	180	6	13	19	27	29	5	10		21	47	83	130	160	8	7
	230	2	4	5	9	11	1	4		0	0	0	0	0	0	0
165	15	(?)	(?)	(?)	0.8	1.2	(?)	(?)	**167**	(?)	0.5	1.0	2.0	3.0	0.5	40*

* Approximate.

Fe, *see* Table 17 (Mn).

H, Mn fused in H is ferromagnetic (40); perhaps hydride is formed. At H = 12 000, σ = 2.2; H_c = 670; d = 7.24; *see* Fig. 47.

N, Mn_3N_2, Mn_5N_2, Mn_7N_2 are ferromagnetic (28, 70); no data.

Ni, *see* Table 20 (Mn).

P, MnP, Mn_3P_2, Mn_5P_2 are ferromagnetic (28, 70).

MnP, Θ = 18 to 26°C

H	85.8	172	343	515	746
I_n	9.2	15.6	22.8	32.8	38.8

S, MnS is ferromagnetic (28, 70); no data.

Sb, Definite compounds of composition MnSb(68.9% Sb), Mn_3Sb_2(59.8% Sb), and Mn_2Sb(52.6% Sb) are formed. For alloys fused in H and cast in red-hot iron molds (32) found:

% Sb	20	40	45	52.2	59.3	68.6	72	90	95	98
H	5259	5244	5211	5353	5274	5238	5401	5421	5414	5276
I_n	62	119	159	176	245	345	317	158	67	37

For Mn_3Sb_2, Θ = 315°C; for Mn_2Sb, Θ = 275°C (32):

MnSb (28, 70) H_c = 8.2; Θ = 320 to 330°C

H	88.9	178	267	356	533	773
I	82	142	188	229	294	361

Mn_2Sb (28, 70) H_c = 33.4

H	70.4	141	211	282	422	612
I	20.4	31.4	43.5	48.5	63.3	74.6

Se, Si, Te, MnSe, MnSi, MnTe are ferromagnetic (28, 70); no data.

Transformation Temperatures

TABLE 22.—TRANSFORMATION POINTS

The Curie point (Θ) is the temperature at which the spontaneous magnetization becomes zero and the material ceases to be ferromagnetic. In intense fields, the change from ferromagnetic to paramagnetic occurs gradually and the intersection of the steeply inclined portion of the (I, t), (σ, t), (I^2, t), or (σ^2, t) curve with the axis of t is generally taken as Θ; this intersection depends upon the intensity of the field; *see* Fig. 39. The following data are arranged in the order Fe, Ni, Co; each is followed by its alloys and compounds, arranged alphabetically by symbol of second constituent. For composition of alloys denoted by key numbers, *see* Table 1.

Fe, Iron. Transformation α to β, Osmond's A_2 point, corresponds to Θ; transformation β to γ corresponds to Osmond's A_3 point, his A_4 point corresponds to transformation γ to δ. In following table + [−] placed after a symbol denotes that the value corresponds to increasing [decreasing] temperature. $\Theta = \Theta_0 + 0.14\sqrt{H}$ (58).

Key	Θ; A_2	A_3+	A_3−	A_4+	A_4−	H	Method	Lit.
2		910 920	905 900	1 407	1 410 1 407		Magnetic	(69)
3	774					10 000	Magnetic	(53)
4		920	920	1 396			Magnetic	(76)
9	784					0	Calorimetric	(85)
9	769	917				0.96	Magnetic	(58)
11		903	903	1 390	1 390		Magnetic	(36)
12		916	890				Magnetic	(35)
12		910	894			0	Thermometric	(35)
27	770				1 420	0	Thermometric	(61)

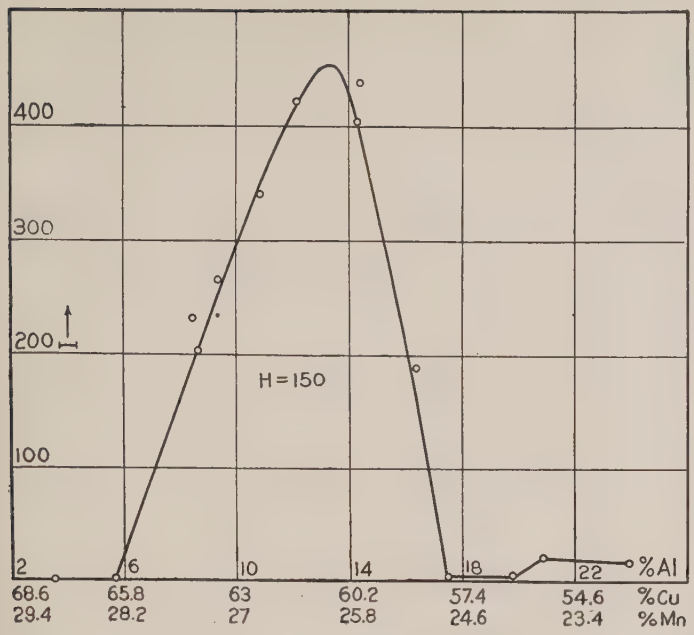

Fig. 44.—Heusler alloy: Variation of magnetization with Al content [29].

Alloys were made by adding Al to a cupromanganese containing 30% Mn.

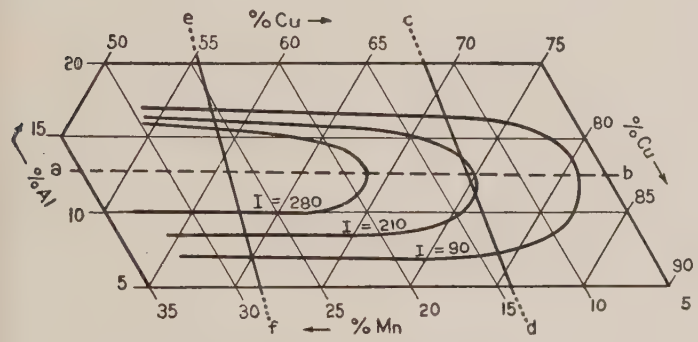

Fig 45.—Aluminum-manganese-copper (Al-Mn-Cu) alloys: Variation of magnetization with composition [29].

H = 150. Line *ab* joins the points $AlCu_3$ and $AlMn_3$. Alloys formed by adding Al to cupromanganese containing 30 and 15% Mn, respectively, lie on the lines *ef* and *cd*. Maximum value of I, about 430, is at intersection of *ab* and *ef*. Each alloy was given a heat treatment which was appropriate to itself. Data are from Table 21.

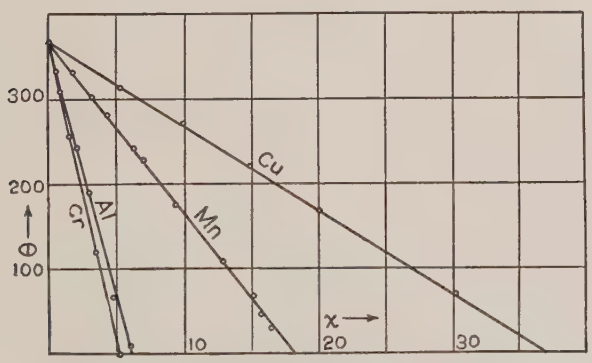

Fig. 48.—Binary alloys of nickel: Curie points [13].
x = % of the constituent named on the curve.

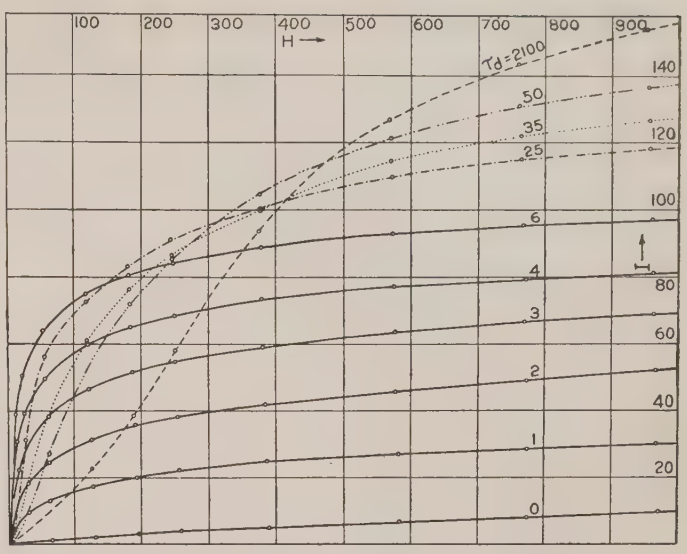

Fig. 46.—Heusler alloy (**156**): Variation of magnetization with heat treatment [67].

Quenched at 600°C and drawn to 209°C for the number of hours indicated on the curves.

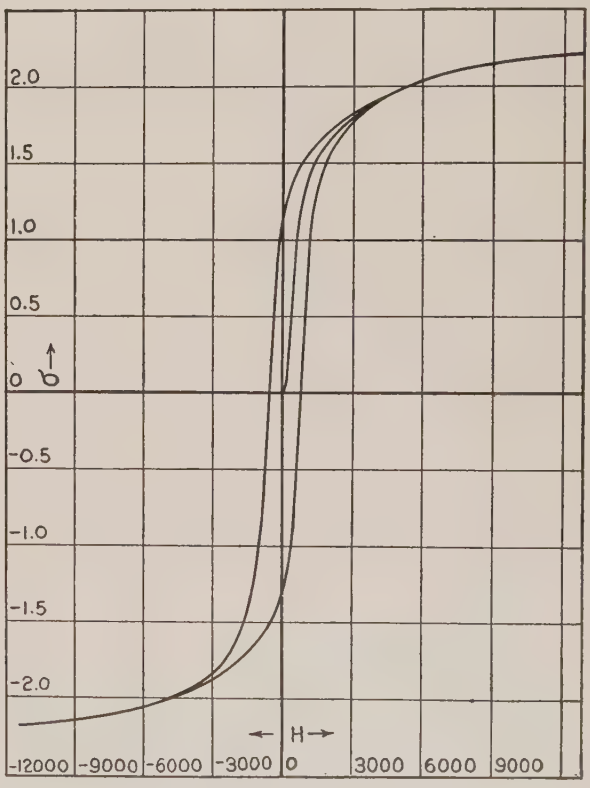

Fig. 47.—Manganese: Magnetization [40].
Mn fused in H; possibly a hydride. H_c = 670; *v.* Table 21.

C, Fe, Fe_3C, Cementite [35], $\Theta = 215°C$.

Co, Fe, Iron cobalt alloys; *see* Table 17 (Co).

Cu, Fe, Iron copper alloys; *see* Table 17 (Cu).

N, Fe, Fe_4N, $\Theta = 390°C$; Fe_2N is not ferromagnetic at room temperatures [17].

Ni, Fe, Iron nickel alloys; *see* Table 17 (Ni).

O, Fe, Magnetite (Fe_3O_4). $\Theta = \Theta_0 + 0.08\sqrt{H}$ (*see* [58]). By magnetic methods [58, 74] $\Theta = 582$ to 586°; by calorimetric methods [85] $\Theta = 585$ to 593°.

Compounds resembling magnetite [8];

$FeO.Fe_2O_3$	$CoO.Fe_2O_3$	$CuO.Fe_2O_3$	$CaO.Fe_2O_3$
$\Theta = 555$	520	418	156°C

Hematite (Fe_2O_3) [41]. Θ is about 600°C. (Temperature corrected on basis of measurement [41] of pyrrhotite.)

S, Fe, Pyrrhotite (FeS with excess of S). Both dilatometric [12] and magnetic [95] methods give $\Theta = 320°C$; *see also* p. 413.

V, Fe, Iron vanadium alloys are ferromagnetic if V < 80%; approximate values, temperature increasing, are [31]: V = 0%, $\Theta = 775°$; V = 20%, $\Theta = 720°$; V = 30%, $\Theta = 600°C$.

Ni, Nickel. For pure Ni [55], $\Theta = \Theta_0 + 0.20\sqrt{H}$. By magnetic measurements [1, 79], Ni fused in H (**145**) or in N (**152**), $\Theta = 357.6$ or 358°C, respectively, by calorimetric measurements [85], Ni (**152**) fused in air, $\Theta = 363°C$.

Al, Ni, Nickel aluminium alloys, *see* Fig. 48.

Co, Ni, Nickel cobalt alloys, *see* Table 20 (Co).

Cr, Ni, Nickel chromium alloys, *see* Fig. 48.

Cu, Ni, Nickel copper alloys, *see* Table 20 (Cu), and Fig. 48.

Fe, Ni, Nickel iron alloys, *see* Table 17 (Ni).

Mn, Ni, Nickel manganese alloys, *see* Fig. 48.

Sn, Ni, Nickel tin alloys [31], ferromagnetic if Sn < 40%.

Sn.....	0	10	20	30	36%
Θ.....	370	320	210	210	210°C (approximate)

Co, Cobalt. By magnetic methods, H small [7, 66], $\Theta = 1075$ to 1115°C; $H = 10\,000$ [53], $\Theta = 1140°C$. By thermometric methods [62], $\Theta = 1102$ to 1112°C.

Cr, Co, Cobalt chromium alloys [31] are ferromagnetic if Cr < 25%.

Cr.....	0	10	15	20%
Θ.....	1140	720	480	180°C (approximate)

Mn, Sb, Manganese antimony alloys, *see* Table 21 (Sb).

Mn, Cu, Al, Heusler alloys [54]:

Key	Mn, %	Al, %	Cu, %	Θ, °C
154	13.9	7.2	78.9	200 to 210
157	6.0	13.2	80.8	300 to 310
158	19.3	14.0	66.6	340 to 350
160	26.5	16.3	57.2	320 to 330
161	11.6	25.0	63.4	5 to 10

For other Mn alloys and compounds, *see* Table 21.

Magnetization of Ferromagnetic Crystals

Fe, Iron. Cubic system; data [5] (Fig. 49 to 54) refer to discs, H lies in plane of disc; σ_p = component of σ parallel to H; σ_n = component in plane of disc and normal to H. φ = azimuth of H with reference to some stated axis of the crystal. Impurities amount to 1.93%, being C = 0.06%, Si = 1.62%, Mn = 0.16%, P = 0.050%, and S = 0.040%.

In each figure (49 to 54) the values of H for the several curves are as follows:

Curve	H	Curve	H
1	17	8	798
2	44	9	1110
3	71	10	1527
4	111	11	2050
5	189	12	4090
6	389	13	6000
7	595	14	9420

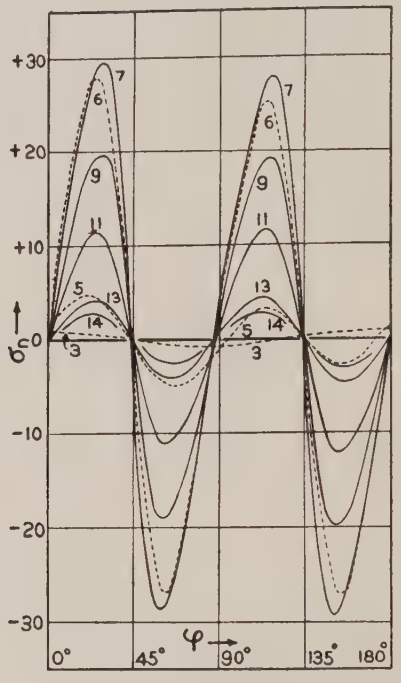

Fig. 49.—Iron crystal.

Figs. 49, 51.—Disc was cut parallel to face of the cube; diameter = 6.90 mm, thickness = 0.090 mm; quaternary axes (edges of cube) at $\varphi = 0°, 90°, 180°$; binary axes (diagonals of faces) at $\varphi = 45°$ and 135°. For values of H, *see* preceding text.

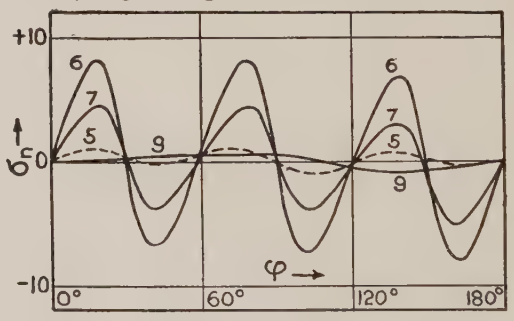

Fig. 50.—Iron crystal.

Figs. 50, 52.—Disc was cut parallel to face of octahedron; diameter = 7.64 mm, thickness = 0.110 mm; binary axes at $\varphi = 0°, 60°, 120°$, and 180°. For values of H, *see* preceding text.

Fe_3O_4, Magnetite. Cubic system: data for the crystal (Fig. 55, 56, 57) apply to Brozzo magnetite at room temperature; for Fig. 56, 57 test piece was a disc 20 mm diameter, 0.3 mm thick. The thermal data (Table 23) refer to a crystalline mass of artificial magnetite, crystals oriented indifferently in all directions; are relative to Kopp's value [39] at 19° and in intense fields, $\sigma = 93.3\left(1 - \frac{19}{H}\right)$; precision about 0.05% except for observations below 17°, those are less reliable on account of doubtful purity. For $t < 500°$, σ_s practically $= \sigma_\infty$; *see also* Tables 3 and 4.

FIG. 51.—(*See* Fig. 49.)

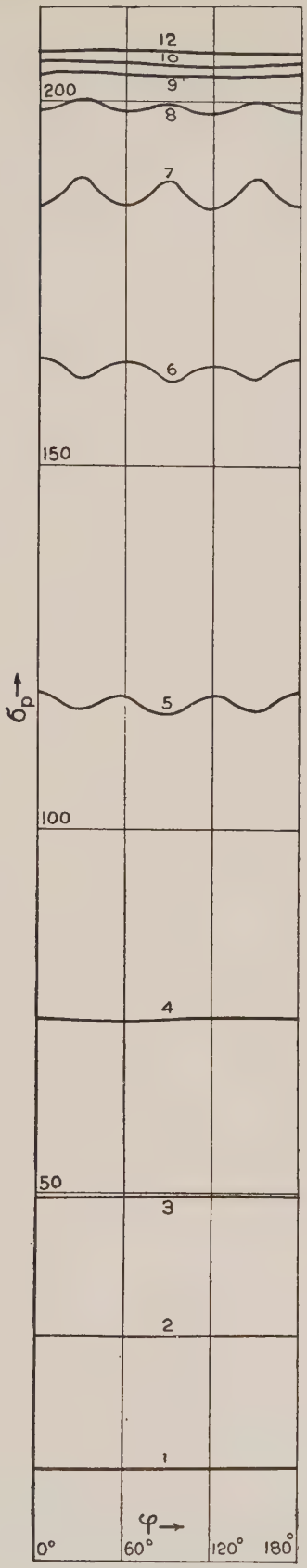

FIG. 52.—(*See* Fig. 50.)

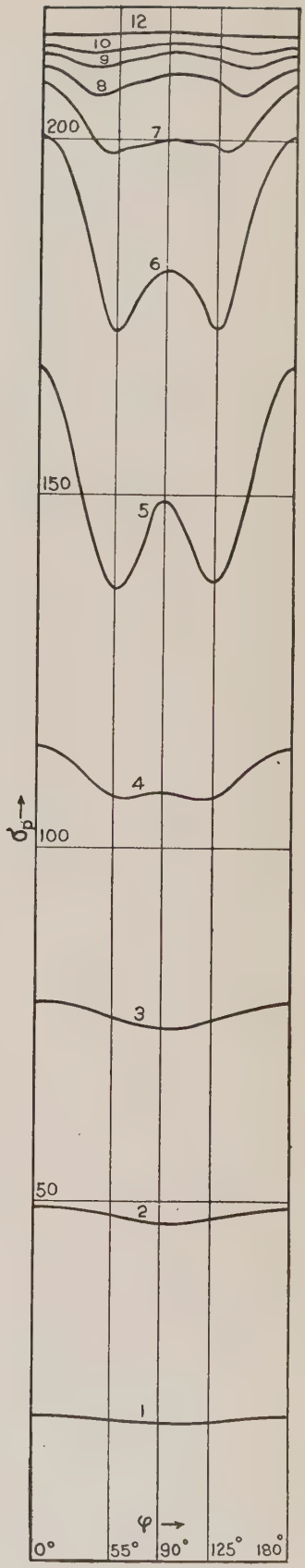

FIG. 53.—(*See* Fig. 54.)

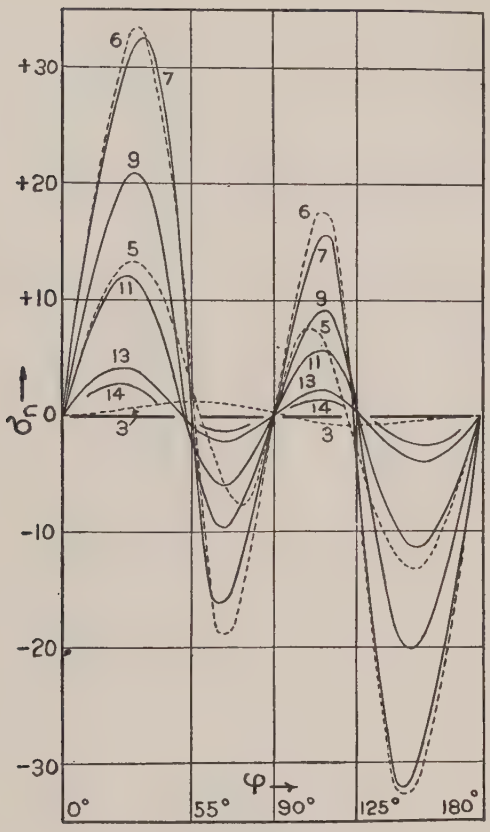

Fig. 54.—Iron crystal.

Figs. 53, 54.—Disc was cut parallel to face of rhombohedral dodecahedron; diameter = 9.20 mm, thickness = 0.085 mm; a quaternary axis lies in the line $\varphi = 0°, 180°$, a binary axis at $\varphi = 90°$, one ternary axis at $\varphi = 54° 44'$ and another at $\varphi = 125° 16'$. For values of H, *see* p. 410.

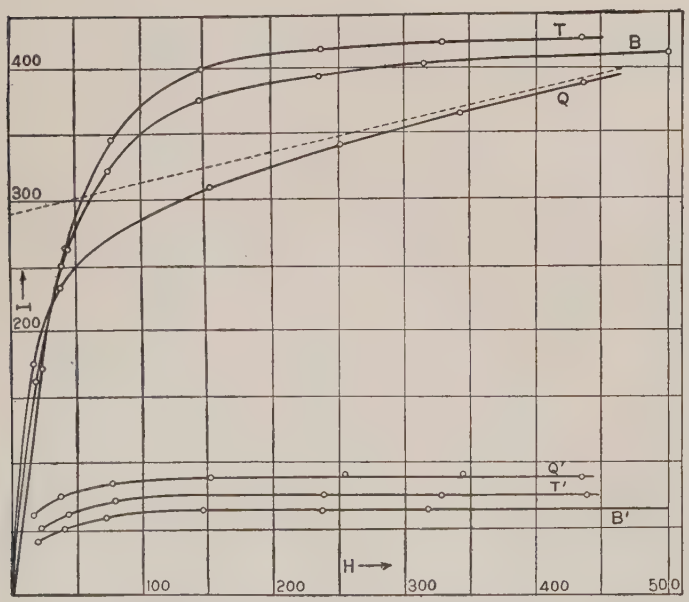

Fig. 55.—Magnetite crystal: Intensity of magnetization (T, B, Q) and residual magnetization (T', B', Q') [71].

B = binary, Q = quaternary, T = ternary axis of crystal. Field H is parallel to the axis considered. Residual magnetization is with reference to $H_{max.} = 353$.

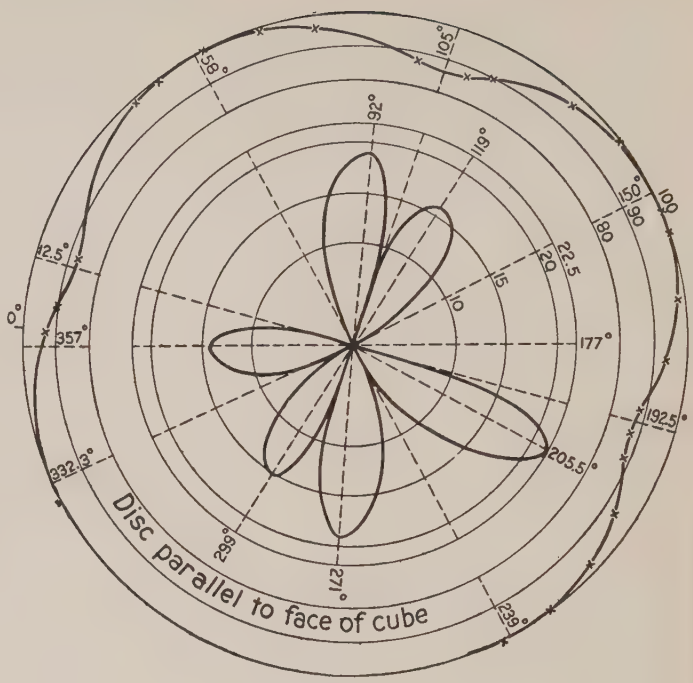

Fig. 56.—(*See* Fig. 57).

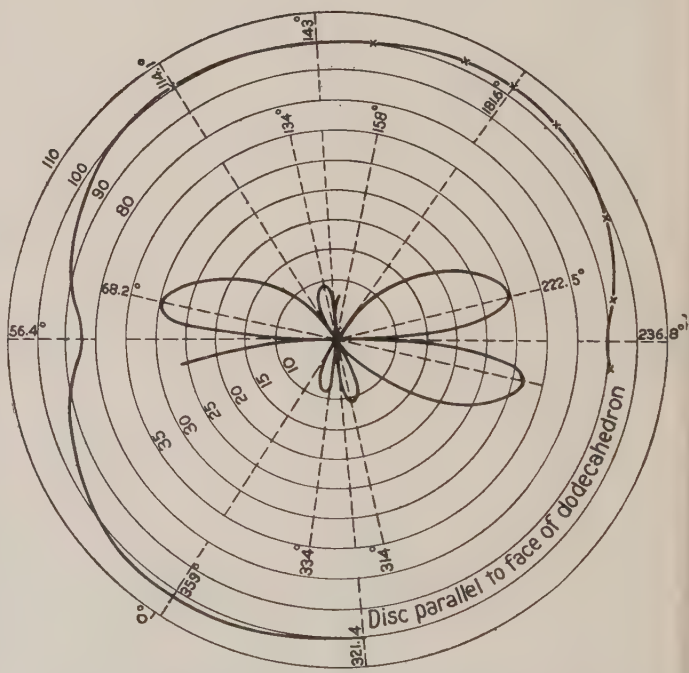

Fig. 57.—Magnetization of disk cut from magnetite crystal [71].

Diameter = 20 mm, thickness = 0.3 mm; $H = 353$ and lies in plane of disk; azimuth (φ) of H is as indicated. I is proportional to length of radius vector of the curve. Inner loops are magnified 3 times as compared with outer curve. Outer curve is for component of I parallel to H; inner curve is for that perpendicular to H. Dotted radii indicate positions of maxima and of minima. For the outer curve: In Fig. 56, maxima correspond to binary, and minima to quaternary axes; in Fig. 57, maxima correspond to ternary, and minima to quaternary and binary axes; *v.* p. 410.

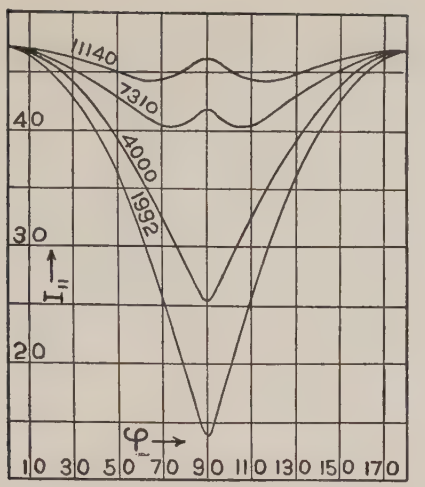

FIG. 58.—Pyrrhotite: Component ($I_{\parallel}$) of the magnetization in the magnetic plane (YOX) and parallel to the field (H) [72].

H lies in plane YOX, φ = azimuth of H from axis (OX) of easy magnetization. Value of H indicated on each curve.

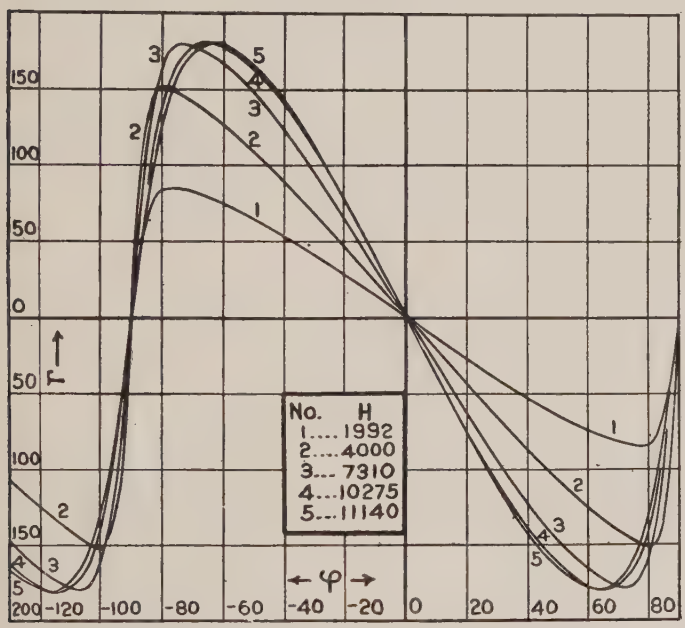

FIG. 59.—Pyrrhotite: Component ($I_{\perp}$) of the magnetization in the magnetic plane (YOX) and perpendicular to the field (H) [72].

H lies in plane YOX, φ = azimuth of H from axis (OX) of easy magnetization. $I_{\perp} = 950\ \Gamma/H$.

TABLE 23.—MAGNETIZATION OF ARTIFICIAL MAGNETITE

t	σ_s	Lit.	t	σ_s	Lit.
−253	98.6	(83)	409.0	61.3	(81)
− 79	96.9	(74)	497.0	45.7	(81)
+ 17.2	93.2	(39)	539.5	33.4	(81)
116.4	88.0	(81)	556.6	25.9	(81)
216.0	81.1	(81)	568.0	18.3	(81)
315.5	72.2	(81)	573.0	13.3*	(81)

* Interpolated. Curie point = 578.3°C.

(Fe_7S_8), Pyrrhotite. Contains variable amounts of dissolved S; analyses vary from Fe_5S_6 to $Fe_{16}S_{17}$. Definite data can be given only for so-called normal pyrrhotite (compact crystals from Morro Velho, d = 4.60); abnormal pyrrhotite (laminar or cleavable, from Bodenmais, etc.) have irregular and complicated properties. Crystals appear to be hexagonal, but magnetic data show that they consist of 3, mutually penetrating, orthorhombic crystals. The data here given refer to the simple orthorhombic crystal.

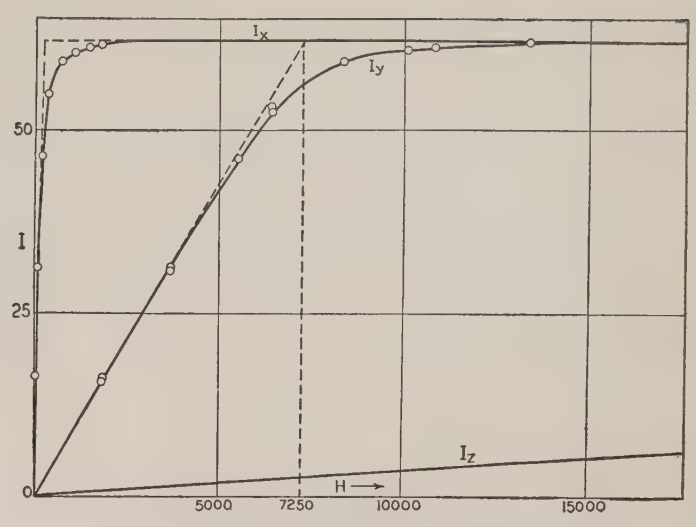

FIG. 60.—Pyrrhotite: Axial magnetization [95].

I_x, I_y, I_z = intensity of magnetization along the principal axes; in every case H is parallel to the axis considered. Maximum H_{Dy} = 7250.

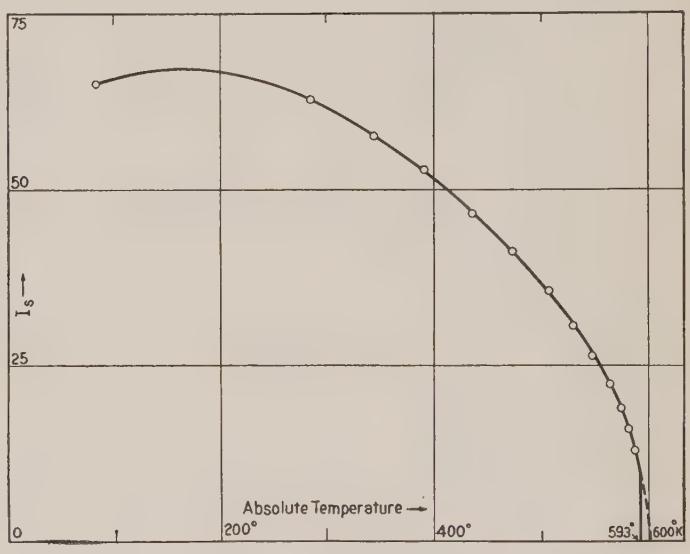

FIG. 61.—Pyrrhotite: Spontaneous magnetization [95].

Except in very intensive fields, I lies approximately in a single plane (base of the apparently hexagonal prism) whatever the direction of H, and the intensity and direction of I depend only upon the component of H in this plane, which is called the magnetic plane of the crystal. In this plane, there is a direction (OX) in which magnetization is easy; in a direction (OY) perpendicular to this, it is difficult. These are the "principal" axes of the crystal. The magnetization of the crystal can be explained by assuming that there is a structural demagnetizing field, component along OY is $H_{Dy} = N_y I_y$, that along OZ (perpendicular to plane of XOY) is $H_{Dz} = N_z I_z$, where I_y, I_z are the components of I along OY, OZ, and N_y, N_z are constants. Maximum values, corresponding to I_∞ are max. H_{Dy} = 7300 gauss [72, 86, 94] and max. H_{Dz} = 176 000 gauss [74, 95]; they are the same for all specimens, but $I_{max.}$ varies with the specimen (*e.g.*, $I_{max.}$ = 47,

63.6, 72.8 (72), 62 (95)). The coercive force also varies with the specimen (H_c = 15.4 (72), 24 (86), 30 (74)). For the specimen of Fig. 58, 59, $I_{max.}$ = 47.

Ferromagnetic properties are lost by an allotropic transformation at 318 to 319°C (76), 320°C (95), which is a little above the Curie point. N_y is independent of the temperature (95); *see* Figs. 58 to 61.

Fe_2O_3, Hematite. Rhombohedral, is sometimes ferromagnetic. Like pyrrhotite, it has an approximate magnetic plane. For hematite from Kragerö, Fe_2O_3 = 93.63%, FeO = 3.26%, TiO_2 = 3.55% (56); for a specimen from same source, the magnetization ($I_\perp$) perpendicular, and that ($I_\parallel$) parallel to the ternary axis were found (87) to be as follows:

H	36	48	60	72
$I_\perp$	1.71	1.78	1.83	1.90
$I_\parallel$	0.025	0.050	0.073	0.093

LITERATURE

(For a key to the periodicals see end of volume)

(1) Alder, *Thesis*, Zürich, 1916. *10*, **4**: 664; 21. (2) Arkadiew, *63*, **14**: 561; 13. (3) Arkadiew, *96*, **27**: 37; 24. (4) Arnold and Elmen, *143*, **195**: 621; 23. (5) Beck, *Thesis*, Zürich, 1918. (6) Binet du Jassonneix, *34*, **142**: 1336; 06. (7) Bloch, *Thesis*, Zürich, 1912. *6*, **26**: 5; 12. (8) du Bois, *in* Gray and Ross, *83*, **8**: 115; 12. (9) Burgess and Aston, *33*, **8**: 79; 10.

(10) Burrows, *31A*, **6**: 31; 09. (11) Cheney, *31A*, **18**: 609; 22. (12) Chevenard, *34*, **172**: 320; 21. (13) Chevenard, *C. R. du congrès du chauffage industriel*, **1**: 157; 23. *In Chaleur et industrie*, **4**: No. 39; 23. (14) Curie, *6*, **5**: 289; 95. (15) Curie, *420*, **3**: 36; 97. (16) Ewing, *5*, **46**: 269; 90. (17) Fry, *77*, **43**: 1271; 23. (18) Gans, *8*, **42**: 1065; 13. (19) Gans, *8*, **48**: 514; 15.

(20) Gans, *8*, **61**: 379; 20. (21) Gray, *3*, **24**: 1; 12. (22) Gumlich, *89*, **4**: 267; 18. (23) Gumlich, *Magnetische Messungen*. Braunschweig, Vieweg, 1918. (24) Gumlich, *in B3*, p. 1195. (25) Gumlich, *96*, **14**: 241; 23. (26) Gumlich and Rogowski, *8*, **34**: 235; 11. (27) Hegg, *Thesis*, Zürich, 1910. (28) Heusler, *88*, **5**: 219; 03. (29) Heusler, Starck and Haupt, *537*, **13**: 23; 504.

(30) Holborn, *8*, **61**: 281; 97. (31) Honda, *8*, **32**: 1003; 10. (32) Honda and Ishiwara, *159*, **6**: 9; 17. (33) Honda and Saito, *159*, **9**: 417; 20. (34) Honda and Shimizu, *3*, **10**: 548; 05. (35) Honda and Takagi, *159*, **4**: 261; 15. (36) Ishiwara, *159*, **6**: 133; 17. (37) Kennelly, *129*, **8**: 485; 91. (38) Kennelly, *143*, **197**: 623; 24. (39) Kopp, *Thesis*, Zürich, 1919. *10*, **5**: 792; 25.

(40) Kuh, *Thesis*, Zürich, 1911. *10*, **2**: 381; 13. (41) Kunz, *190*, **1907 I**: 62. (42) Lapp, *51*, **4**: 349; 23. (43) Lonsdale, *63*, **14**: 581; 13. (44) Maurain, *6*, **20**: 353; 10. (45) Moir, *3*, **27**: 830; 14. (46) Mordey, *121*, **66**: 615; 11. (47) Nusbaum, Cheney and Scott, *31A*, **16**: 739; 20. (48) Perrier, *Thesis*, Zürich, 1909. (49) Perrier and Balochowsky, *149*, **2**: 5; 20.

(50) Perrier and Onnes, *168*, **Suppl. No. 27**; 13. (51) Peschard, *Thesis*, Strasbourg, 1925. (52) Pierce, *65*, **49**: 117; 13. (53) Preuss, *Thesis*, Zürich, 1912. *10*, **3**: 286; 14. (54) Preusser, *Thesis*, Marburg, 1908. (55) Radovanović, *Thesis*, Zürich, 1911. (56) Rammelsberg, *8*, **104**: 497; 58. (57) Rayleigh, *3*, **23**: 225; 87. (58) Renger, *Thesis*, Zürich, 1913. *10*, **4**: 663; 22. (59) Renker, *Thesis*, Zürich, 1913. *10*, **4**: 664; 22.

(60) Ross and Gray, *68*, **29**: 274; 09. (61) Ruer and Fick, *139*, **11**: 39; 13. (62) Ruer and Kaneko, *192*, **9**: 419; 12. (63) Safranek, *74*, **21**: 87; 24. (64) Sanford and Cheney, *31A*, **16**: 291; 20. (65) Steinhaus and Gumlich, *125*, **4**: 149; 15. (66) Stifler, *2*, **33**: 268; 11. (67) Take, *88*, **12**: 1059; 10. (68) Terry, *2*, **30**: 133; 10. (69) Terry, *2*, **9**: 394; 17.

(70) Wedekind, *7*, **66**: 614; 09. (71) Weiss, *Thesis*, Paris, 1896. (72) Weiss, *51*, **4**: 469, 829; 05. (73) Weiss, *51*, **9**: 373; 10. (74) Weiss, P., *0*. (75) Weiss and Foëx, *51*, **1**: 274, 744; 11. (76) Weiss and Foëx, *149*, **31**: 39; 11. (77) Weiss and Foëx, *Le Magnétisme*. Paris, Armand Colin, 1926. (78) Weiss and Forrer, *34*, **178**: 1046; 24. (79) Weiss and Forrer, *34*, **178**: 1670; 24.

(80) Weiss and Forrer, *34*, **186**: 821; 28. (81) Weiss and Forrer, *0*. (82) Weiss and de Freudenreich, *149*, **39**: 125; 15. (83) Weiss and Onnes, *64V*, **18**: 768; 10. *168*, **No. 114**; 10. *51*, **9**: 555; 10. (84) Weiss and Piccard, *34*, **166**: 352; 18. (85) Weiss, Piccard and Carrard, *149*, **42**: 378; 16. **43**: 22, 113, 199; 17. (86) Weiss and Planer, *51*, **7**: 5; 08. (87) Westmann, *Diss.*, Upsala, 1896. (88) Williams, *2*, **6**: 404; 15. (89) Wvedensky, *8*, **66**: 110; 21.

(90) Yensen, *86*, **No. 72**; 14. (91) Yensen, *86*, **No. 77**; 15. (92) Yensen, *86*, **No. 83**; 15. (93) Yensen, *39*, **39**: 396; 20. (94) Yensen, *129*, **43**: 145; 24. (95) Ziegler, *Thesis*, Zürich, 1915.

GALVANOMAGNETIC AND THERMOMAGNETIC EFFECTS

Alpheus W. Smith and L. L. Campbell

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The effects considered are the Hall, Ettingshausen, Nernst, and Righi-Leduc effects, and the changes which a magnetic field produces in the electrical and the thermal conductivities. For a detailed account of the several effects, *see* (15). Most of these data depend very greatly upon the crystalline structure, purity, and treatment of the material. Variations in these factors, which at present are not specifiable in a satisfactory manner, produce in the numerical data variations which exceed the usual errors of measurement. For this reason, it has not been possible to calculate most probable values from the available data, and it has seemed necessary, for the most part, to tabulate what seemed the most trustworthy values.

If upon a thin, flat, conducting plate P (width = b, thickness = d), carrying a uniform, constant, longitudinal current (total current = I) of either electricity or heat, there be imposed normally a magnetic field of intensity H, there are set up, for either type of current, two transverse and two longitudinal effects which may be simply expressed in terms of H, I, b, and d. Referring to

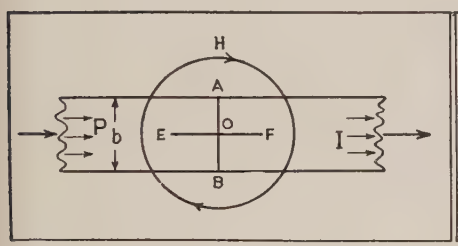

FIG. 1.

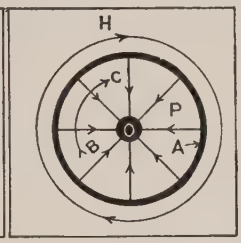

FIG. 2.

FIG. 1.—Diagram for illustrating galvanomagnetic and thermomagnetic effects. P is a thin, flat, conducting plate of width b and thickness d, carrying the uniformly distributed, constant, longitudinal current I and placed in a uniform, transverse magnetic field H having the direction that corresponds to Amperian currents flowing in the direction indicated by the arrows on the circle.

FIG. 2.—Diagram illustrating the Corbino effect. P is a thin, flat, circular, conducting ring connecting the massive electrodes O of radius r_1 and A of radius r_2. If, while a uniform radial electric current flows from A to O, the plate be subjected to a uniform, transverse magnetic field H having the direction that corresponds to Amperian currents in the direction indicated by the arrows on the outer circle, a circular current in the direction BC will be set up if the Corbino effect is positive.

Fig. 1, if, in the absence of the field, AB is an equipotential and an isothermal line, and if the direction of H is that corresponding to Amperian currents flowing in the direction indicated by the arrows on the circle, then the effects corresponding to the positive values of the several coefficients are as follows:

Galvanomagnetic Effects.—(I = current of electricity.) (1) *Hall effect;* coefficient $\equiv R$. Potential at A becomes greater than that at B by an amount E; $R = Ed/HI$. (2) *Ettingshausen effect;* coefficient $\equiv P$. Temperature at A becomes higher than that at B by an amount ΔT; $P = d\Delta T/HI$. (3) The difference in potential between E and F is changed; that is, the longitudinal electrical resistance is changed. (4) The difference in temperature between E and F is changed.

If in measuring the Hall effect, the conditions are such that there is a negligible transfer of heat between the plate and other bodies, the temperature at A will differ from that at B, and, for some substances, the value found for R will be a little different from that which is found when the strip is maintained at a uniform temperature. The latter is called the *isothermal*, and the former, the *adiabatic* Hall effect.

Thermomagnetic Effects.—(I = current of heat; dT/dx = longitudinal temperature gradient along the plate in the direction opposite to that of the flow of the heat.) (1) *Nernst effect;* coefficient $\equiv Q$. Potential at A becomes greater than that at B by an amount E. $Q = E/[Hb(dT/dx)]$. (2) *Righi-Leduc effect;* coefficient $\equiv S$. Temperature at A becomes greater than that at B by an amount ΔT. $S = \Delta T/[Hb(dT/dx)]$. (3) The difference in potential between E and F is changed. (4) The difference in temperature between E and F is changed; that is, the longitudinal thermal conductivity is changed.

If either E or ΔT is negative, so is the corresponding coefficient. By multiplying the expressions for Q and S by the heat conductivity per unit length of the plate, they become of the same form as the expressions for R and P.

Hall Effect (31) (R).—Differences in the values obtained, under apparently the same conditions, by different observers may be due to the presence of impurities, or to differences in the physical condition of the material. For *non-magnetic metals*, with the exception of Sb, Bi, and Te, R varies very little with T and practically not at all with H. For the *ferromagnetic metals*, R, generally, increases with T until the Curie point is reached, then it decreases rapidly, and probably becomes 0 at the melting point; for T constant, R at first is independent of H, then decreases as H increases, and in higher fields approaches a limiting value.

Corbino Effect (18).—If, instead of being longitudinal, the electric current (I) radiates from O (Fig. 2), the imposition of H sets up a circular current around O. This is the *Corbino effect.* If the plate is a circular annulus of radii r_1 and $r_2 (r_1 < r_2)$, if the radial current has a uniform angular distribution, the total current towards the center being I, and if the field (H) is uniform over the entire plate, then the total value of the circular current (C) set up in the plate in the direction of the Amperian currents corresponding to H is $C = \frac{cHI}{2\pi} \log_e \frac{r_2}{r_1}$; c is the Corbino constant. On Adams' theory (1) $c = \mu_0 e t_0/2m$, where t_0 = free time of an electron, μ_0 is the magnetic permeability of a vacuum, and e and m are the charge and mass of an electron. In many cases, t_0 is negative; this means that the theory is not satisfactory. Fundamentally, the Corbino and the Hall effects are of the same nature (1), but it is the product of c times the specific resistance of the plate, which is comparable with R (17).

Change in Resistance.—When a conductor is placed in a magnetic field (H), its resistance (r) in any specified direction with reference to H is increased by an amount which may vary with the direction of the field. For *non-magnetic* metals and alloys, $\Delta r/r$, at constant temperature, is nearly proportional to H^2. Writing $\Delta r/r = CH^2$, C is generally of the same sign (+ for pure metals, − for alloys) for all directions; its numerical value increases rather rapidly as the temperature is reduced, and varies only slightly, if at all, with H. For Bi, Sb, and graphitic C, the relation between Δr and H is abnormal. For *ferromagnetic* metals, $\Delta r/r$, except at extremely low temperatures, is nearly proportional to the intensity of magnetization. For Co and Ni, Δr is negative if transverse to the field, and positive if parallel to it As the field is increased, the numerical value of Δr increases in both cases, approaching a limiting value in intense fields. As the transverse field is increased, Δr changes at first slowly, then more rapidly, and finally slowly again. As the longitudinal field is increased, Δr changes rapidly at first, then more slowly. Small errors in the orientation of the transverse field lead to positive values of Δr in weak fields; this may account for some of the reported initial positive values of Δr in transverse fields. Iron behaves differently.

TABLE 1.—HALL EFFECT (R): ELEMENTARY SUBSTANCES

$R = Ed/HI$; $R = A \times 10^{-n}$; t_R = room temperature; unit of H = 1000 cgsm = 1 kilogauss; of R = 1 cgsm = 10^{-9} volt-cm/ampere-gauss; t = temperature, °C.

	t	H	A	n	Lit.
Ag	t_R	9 to 12	− 8.32	4	(20)
	t_R	*	− 8.38	4	(74)
	20	5 to 11	− 8.97	4	(80)
	17	10	− 7.95	4	(7)
Al	t_R	9	− 3.85	4	(20)
	14	21	− 3.96	4	(74)
	18	*	− 3.90	4	(3)
As	20	4 to 8	+ 4.52	2	(46)
Au	25	9.3	− 7.04	4	(34)
	t_R	9.0	− 7.11	4	(20)
	18	*	− 7.04	4	(3)
	17	12	− 7.24	4	(7)
Bi	20	1.13	− 10.1	0	(20)
	18	10.6	− 4.82	0	(79)
	14.5	0.89	− 5.78	0	(73)
C	t_R	4 to 11	− 1.73	1	(20)
	90	10.3	− 1.6	1	(79)
	17	11.8	+ 7.4†	1	(57)
Cd	t_R	9 to 12	+ 5.5	4	(20)
	t_R	*	+ 8.8	4	(74)
	18	*	+ 5.89	4	(3)
	17	12.0	+ 5.5	4	(57)
Ce	24	17.5	+ 1.92	3	(68)
Co	t_R	*	+ 2.45	3	(74)
	24	4.4	+ 1.61§	3	(79)
	25	9.3	+ 3.72	3	(34)
Cu	16	8 to 22	− 5.47	4	(74)
	t_R	12.0	− 5.19	4	(20)
	20	*	− 5.4	4	(79)
	20	5 to 11	− 4.28	4	(80)
	18	*	− 5.28	4	(3)
	17	10	− 4.92	4	(7)
Fe‡	13	8 to 15	+ 9.08	3	(74)
	12.9	5.3	+ 7.94	3	(35)
	18	6.3	+ 10.8	3	(79)
	22	17.0	+ 11.0	3	(64)
	18	*	+ 11.2	3	(3)
	t_R	2.5	+ 17.5‖	3	(20)
	t_R	5 to 11	+ 13.4‖	3	(80)
In	24	17.5	− 0.73	4	(68)
Ir	20	5 to 11	+ 4.02	4	(80)
	20	5 to 11	+ 3.64	4	(80)
Li	24	17.5	− 1.70	3	(68)
Mg	t_R	7.4	− 9.4	4	(20)
Mn	t_R	*	− 9.3	4	(81)
Mo	24	17.5	+ 1.26	3	(68)
Na	t_R	8.7	− 2.5	3	(20)
Ni	37.5	9.3	− 5.10	3	(34)
	14	2.0	− 8.46	3	(74)
	18	6.3	− 12.5	3	(79)
	18	10.6	− 4.69§	3	(79)
	18	*	− 4.70	3	(3)
Pb	20	11 to 16	+ 0.9	4	(20)
	−269	11.3	+ 1.8	4	(57)
Pd	25	9.3	− 8.44	4	(34)
	20	5 to 11	− 6.91	4	(80)
	20	6 to 13	− 11.5	4	(20)
	20	5 to 11	− 11.1	4	(80)
	17	9.8	− 6.80	4	(7)
Pt	20	12.0	− 2.4	4	(20)
	20	5 to 11	− 1.27	4	(80)
	18	*	− 2.02	4	(3)
Sb	20	4 to 16	+ 1.92	1	(20)
	21.5	1.8	+ 2.19	1	(5)
	18	*	+ 2.19	1	(79)
	18	*	+ 1.25	1	(3)
Si	23	20	+ 41.0	0	(64)
	50	9	+ 23.0	0	(13)
	18.7	6.2	+206.0¶	0	(28)
	18.7	6.2	+120.0**	0	(28)
Sn	t_R	4	− 0.2	4	(32)
	t_R	5.0	− 0.36	4	(20)
	−269	11.3	+ 0.26	4	(57)
Ta	24	17.5	+ 1.01	3	(68)
Te	20	3 to 9	+530.0	0	(20)
	27	5	+784.0	0	(77)
	22	8.8	+536.0	0	(67)
	20	8.8	+621.0	0	(67)
Tl	24	17.5	+ 2.4	4	(68)
W	24	17.5	+ 1.18	3	(68)
Zn	t_R	6 to 10	+ 4.10	4	(20)
	16	8 to 21	+ 9.53	4	(74)
	20	5 to 11	+ 10.4	4	(80)
	22	25	+ 3.3	4	(5)

* Magnetic field not stated by observer.

† Graphite.

‡ Recent observations (76,1) show that in single crystals of Fe, R varies but little with the directions of the axes of the crystal, and differs but little from its value for soft iron.

§ Electrolytic.

‖ Steel.

¶ Isothermal.

** Adiabatic.

TABLE 2.—HALL EFFECT (R): MISCELLANEOUS MATERIALS

For elementary substances and alloys, *see* Tables 1 and 3; $R = A \times 10^n$; ρ = volume resistivity of $Cu_2I_2 + kI$; unit of R = 1 cgsm = 10^{-9} volt-cm/ampere-gauss; of ρ = 1 ohm-cm.

Material	t	A	n	Lit.	$Cu_2I_2 + kI$ (72) ρ‡	A‡	n
Cu_2I_2, Cuprous iodide	18	+ 11	+3	(72)	0.02	55	−2
					0.049	20	−1
FeS_2, Pyrites	18	−296	−3	(67)	0.12	69	−1
					2.91	34	+1
MoS_2, Molybdenite	18	−260*	+1	(41)	0.212	20	+1
	90	− 88*	+1	(41)	7.50	88	+1
	18	−131†	+1	(41)	94.0	11	+3
	90	− 49†	+1	(41)			
	18	−303*	+1	(28)			
	90	−878*	0	(28)			
	18	−152†	+1	(28)			
	90	−481†	0	(28)			

* Adiabatic.

† Isothermal.

‡ Cu_2I_2 dissolves I; both ρ and A decrease as the amount of the dissolved I increases; amount of I dissolved is not stated.

TABLE 3.—HALL EFFECT (R): ALLOYS

C_1 = proportion of constituent (1); unit of C_1 = 1% by wt.; $R = 10^{-3}$ cgsm $= 10^{-12}$ volt-cm/ampere-gauss; H = 1000 cgsm = 1 kilogauss; temperatures (t) in °C.

Alloy	C_1	R			
	t =	−258.6°	−252.8°	−183°	+17°C
(1) Au, Gold	0	−0.99	−1.015	−0.82	−0.80
	3.95	−0.69	−0.695	−0.74	−0.77
(2) Ag, Silver (55, 56)	15.47	−0.575	−0.575	−0.645	−0.735
	44.28	−0.44	−0.45	−0.52	−0.60
	81.00	−0.37	−0.36	−0.47	−0.56
	93.84	−0.37	−0.37	−0.525	−0.56
	98.89	−0.65	−0.67	−0.66	−0.68
	100.00	−0.98	−0.98	−0.76	−0.72

Alloy	C_1	R
(1) Cu, Copper	0	+ 0.830
	6	+ 0.496
(2) Zn, Zinc (33)	67	− 0.116
	73	− 0.250
	81.3	− 0.404
	100	− 0.520
(1) Fe, Iron	92.95	+15.2
	93.84	+15.6
(2) Cu, Copper (69)	96.0	+16.3
	98.0	+19.0
	98.49	+21.0
	99.196	+12.2
	100	+11.2
(1) Ni, Nickel	50	− 1.33
	65	− 6.31
(2) Cu, Copper (69)	70	−41.9
	75	−83.7
	85	−59.1
	90	−52.0
	92.5	−40.9
	95	−29.8
	100	− 7.65
(1) Ni, Nickel	0	+11.2
	1.07	+16.9
(2) Fe, Iron (69)	1.93	+17.8
	7.05	+42.5
	8.17	+43.1
	10.20	+52.0
	13.11	+61.5
	56.0	+46.9
(1) Sn, Tin	0	− 9.84
	0.95	− 1.76
(2) Bi, Bismuth; unit of R = 1 cgsm = 10^{-9} volt-cm per ampere-gauss (22).	1.46	− 0.69
	H = 2 kilogauss	
	0	− 7.20
	0.95	− 0.53
	1.46	− 0.07
	6.14	+ 0.01
	H = 6 kilogauss	
	0	− 4.98
	0.95	+ 0.12
	1.46	+ 0.36
	6.14	+ 0.09
	H = 11 kilogauss	

Constantan (80) 60Cu + 40Ni
R = −0.9

Monel (67)*

H	t	R
1.65	25	− 35.1
1.65	66	− 24.2
3.15	96	− 9.62
5.30	137	− 2.38

Nichrome (67)

H	t	R
3.3	17	+199
3.3	120	+209
1.05	198	+200
1.05	216	+113
3.3	246	+ 21.2
5.5	286	+ 8.6

German silver (21)
50Cu + 30Zn + 20Ni
R = −0.54

Manganin (27)
84Cu + 12Mn + 4Ni

H	t	R
4.1	150	0.569†
4.79	440	0.432†
4.92	810	0.460†

Heusler alloy‡ (81)
25Mn + 15Al + 60Cu
R = +13.0

* Ni, 68%; Cu, 29.5%; Fe, 1.5%; Mn, 1%.

† Sign of R is not given by observer.

‡ R is +, but for each constituent it is −.

TABLE 4.—VARIATION OF HALL EFFECT (R) WITH TEMPERATURE (T)

A-Table.—Elementary Substances

Unit of $R = 10^{-5}$ cgsm $= 10^{-14}$ volt-cm/ampere-gauss; T is abs. temp., °K

Ag, Silver

T	R	Lit.	T	R	Lit.
2.8	−160	(57)	290	− 80	(55, 56)
4.25	−160	(57)	83	− 92	(64)
14.5	− 99.1	(55, 56)	296	− 84	(64)
20.3	−101.4	(55, 56)			

TABLE 4.—(*Continued*)

Al, Aluminium

T	R	Lit.
20	− 24.8	(3)
83	− 20.0	(3)
194	− 39.0	(3)
291	− 39.0	(3)
83	− 19.2	(64)
298	− 32.0	(64)

Au, Gold

20	− 85.7	(3)
83	− 72.6	(3)
194	− 71.2	(3)
291	− 70.4	(3)
14.5	− 98.2	(7, 55, 56)
20.3	− 98.1	(7, 55, 56)
290	− 72.4	(7, 55, 56)
83	− 72.5	(64)
298	− 70.4	(64)
298	− 70.4	(34)
328	− 69.9	(34)

Bi, Bismuth
See Table 5

C, Carbon
See Table 5

Cd, Cadmium

20	+203	(3)
83	+ 79.5	(3)
194	+ 60.5	(3)
291	+ 58.9	(3)
14.5	+191	(57)
20.5	+176	(57)
290	+ 55	(57)

Co, Cobalt
See Table 5

Cu, Copper

20	− 60.5	(3)
83	− 79.2	(3)
194	− 55.3	(3)
291	− 52.8	(3)
14.5	− 65.6	(7)
20.3	− 66.2	(55, 56)
290	− 49.2	(55, 56)

Cu.—(*Continued*)

T	R	Lit.
83	− 65	(64)
296	− 54	(64)
289	− 53.2	(74)
373	− 54.6	(74)

Fe, Iron
See Table 5

Ni, Nickel
See Table 5

Pb, Lead

2.8	+ 13	(57)
4.25	+ 18	(57)

Pd, Palladium

14.5	−138.5	(7, 55, 56)
20.3	−136.8	(7, 55, 56)
290	− 67.5	(7, 55, 56)
83	−109	(64)
296	− 86	(64)
298	− 84.4	(34)
318	− 85.5	(34)
338	− 84.3	(34)

Pt, Platinum

20	− 19.9	(3)
83	− 19.8	(3)
194	− 9.04	(3)
291	− 20.2	(3)
83	− 22.2	(64)
296	− 20.2	(64)

Sb, Antimony
See Table 5

Sn, Tin

2.8	+ 9.8	(57)
4.25	+ 2.6	(57)

Te, Tellurium
See Table 5

Zn, Zinc

83	+109	(64)
298	+ 63	(64)
353	+ 53.0	(27)
473	+ 44.6	(27)
673	+ 63.4	(27)
289	+ 94.6	(74)
374	+ 85.2	(74)

TABLE 5.—VARIATION OF HALL EFFECT (R) WITH TEMPERATURE (T): BI, C, CO, FE, NI, SB, AND TE

$R = A \times 10^n$ cgsm $= A \times 10^{n-9}$ volt-cm/ampere-gauss; T = abs. temp., °K

Bi, Bismuth; n = 0

T	A	Lit.
4.25	− 86.3	(57)
287.5	− 5.78	(73)
377	− 2.83	(73)
530	− 1.13	(73)
543	− 0.25	(73)
14.6	− 69.5	(7, 55, 56)
20.3	− 59.0	(7, 55, 56)
73.0	− 33.5	(7, 55, 56)
90.0	− 24.6	(7, 55, 56)
290.0	− 5.66	(7, 55, 56)

C, Carbon (Graphite); n = 0

T	A	Lit.
14.5	+ 1.52	(57)
20.5	+ 2.22	(57)
290	+ 0.74	(57)

Co, Cobalt;* n = −3

298	+ 3.72	(34)
318	+ 4.34	(34)
83	+ 1.51	(64)
296	+ 5.88	(64)
373	+ 8.65	(64)
457	+ 13.6	(64)

TABLE 5.—(*Continued*)

Co.—(*Continued*)		
T	*A*	Lit.
573	+ 21.2	(64)
789	+ 48.3	(64)
933	+ 89.4	(64)
1113	+158	(64)
1233	+200	(64)
1303	+170	(64)
1373	+ 60	(64)
Fe, Iron;† $n = -3$		
20	+ 1.44	(3)
83	+ 1.33	(3)
194	+ 4.99	(3)
291	+ 11.23	(3)
83	+ 0.75	(64)
295	+ 11.0	(64)
373	+ 18.9	(64)
457	+ 29.2	(64)
573	+ 50.4	(64)
818	+167	(64)
917	+243	(64)
1008	+319	(64)
1069	+120	(64)
1108	+ 32.8	(64)
1173	+ 9	(64)
286	+ 7.94	(35)
358	+ 14.86	(35)
Ni, Nickel;‡ $n = -3$		
20	− 1.52	(3)
83	− 1.38	(3)
194	− 2.80	(3)
291	− 4.70	(3)
4.25	− 0.00+	(57)

Ni.—(*Continued*)		
T	*A*	Lit.
20.3	− 0.468	(7, 55, 56)
90	− 0.798	(7, 55, 56)
290.5	− 4.37	(7, 55, 56)
83	− 1.85	(64)
296	− 12.7	(64)
373	− 16.3	(64)
457	− 23.4	(64)
573	− 40.8	(64)
628	− 56.0	(64)
658	− 58.9	(64)
666	− 19.2	(64)
683	− 4.5	(64)
819	− 0.7	(64)
310	− 5.10	(34)
330	− 5.93	(34)
350	− 6.83	(34)
Sb, Antimony; $n = -3$		
20	+152	(3)
83	+163	(3)
194	+140	(3)
291	+125	(3)
87	+245	(5)
194	+235	(5)
295	+209	(5)
331	+203	(5)
Te, Tellurium; $n = 0$		
14.5	+211	(7, 55, 56)
20.3	+214.5	(7, 55, 56)
89	+210.5	(7, 55, 56)
291	+185.5	(7, 55, 56)

* *See also* Fig. 5. † *See also* Fig. 3. ‡ *See also* Fig. 4.

TABLE 6.—VARIATION OF HALL EFFECT (R) WITH MAGNETIC FIELD (H)

Cf. p. 416, 417 and Figs. 3, 4, 5; T = abs. temp., °K; t = centigrade temp., °C; unit of $R = 1$ cgsm $= 10^{-9}$ volt-cm/ampere-gauss; $H = 1000$ cgsm $= 1$ kilogauss.

Bi, Bismuth (26)					
H \ *T*	91°	183°	250°	284.5°	373°K
1	−62.2	−28.0	−17.0	−13.3	−7.28
2	−55.0	−25.0	−16.0	−12.7	−7.17
3	−49.7	−22.9	−15.1	−12.1	−7.06
4	−45.8	−21.5	−14.3	−11.55	−6.95
5	−42.6	−20.2	−13.6	−11.05	−6.84
6	−40.1	−18.9	−12.9	−10.6	−6.72

Bi (5)		Sb, Antimony (5)	
H \ *t*	14	*H* \ *t*	21.5
2	−3.8	0.14	+0.26
4	−3.3	0.72	+0.21
6	−3.0	1.75	+0.21
8	−2.7	4.31	+0.208
10	−2.4	8.19	+0.201
11	−2.3	10.20*	+0.199

* $H = 19.2$, $R = +0.189$; $H = 24.7$, $R = +0.186$.

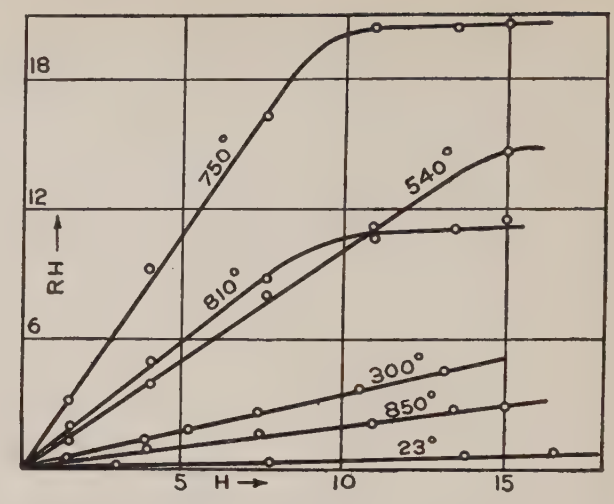

FIG. 3.—Hall effect (R) in electrolytic iron (64). Unit of RH is undetermined, of $H = 1$ kilogauss; temperatures are °C; *see also* Tables 1, 5.

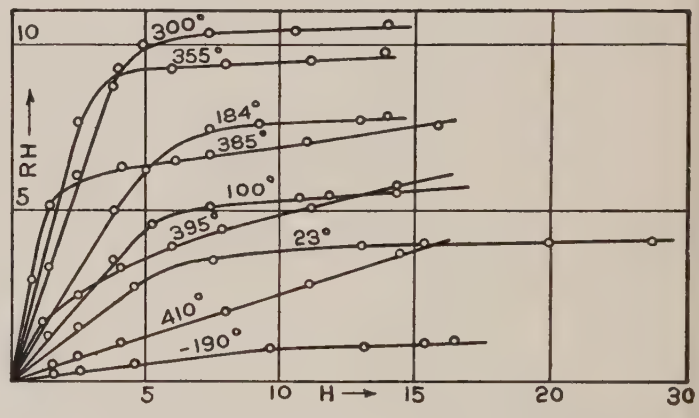

FIG. 4.—Hall effect (R) in nickel (64). Unit of RH is undetermined, of $H = 1$ kilogauss; temperatures are °C; *see also* Tables 1, 5.

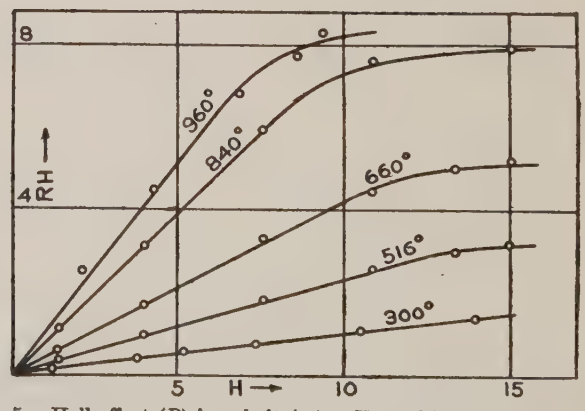

FIG. 5.—Hall effect (R) in cobalt (64). Unit of RH is undetermined; of $H = 1$ kilogauss; temperatures are °C; *see also* Tables 1, 5.

TABLE 7.—CORBINO EFFECT (c) ([2, 17])

See Fig. 2; unit of H = 1000 cgsm = 1 kilogauss; $c = 10^{-7}$ cgsm = 10^{-7} gauss^{-1}

Ag, Silver	
H	c
4.58	− 4.84
5.51	− 4.86
6.24	− 5.05
6.90	− 4.78

Al, Aluminium	
5.66	− 0.83
6.85	− 0.69
7.97	− 0.77

Au, Gold	
5.25	− 2.06
6.64	− 1.99

Bi, Bismuth	
0.03	−711
0.107	−739
0.419	−771
0.953	−666
2.63	−613
4.69	−520

Bi.—(*Continued*)	
H	c
5.82	−443
6.54	−415
7.72	−381

Cd, Cadmium	
7.21	+ 0.715

Co, Cobalt	
5.36	+ 2.63
6.69	+ 2.61
7.57	+ 2.48

Cu, Copper	
2.82	− 3.36
4.22	− 2.40
5.92	− 2.61
6.75	− 2.51
7.31	− 2.38

Fe, Iron	
1.39	+ 7.45
2.06	+ 8.27
3.30	+ 6.55
4.89	+ 6.64

Fe.—(*Continued*)	
H	c
6.75	+ 6.58
7.62	+ 6.60
8.45	+ 7.13

Ni, Nickel*	
2.57	− 14.4
3.73	− 14.5
4.81	− 14.6
5.97	− 13.0
6.93	− 11.76

* *See also* Table 8.

Pt, Platinum	
7.06	− 0.199

Sb, Antimony	
2.59	+ 40.9
4.38	+ 40.7
6.18	+ 38.3
7.21	+ 37.5

Zn, Zinc	
7.47	+ 0.343

TABLE 8.—RELATION BETWEEN HALL (R) AND CORBINO (c) EFFECTS, AND FREE TIMES (t_0) OF ELECTRONS

Illustrative only; *see* p. 415; same specimen used for R, ρ, and c, except as indicated; ρ = electrical volume resistivity; unit of $c = 10^{-6}$ cgsm = 10^{-6} gauss^{-1}; H = 1000 cgsm = 1 kilogauss; $R = 10^{-2}$ cgsm = 10^{-11} volt-cm/ampere-gauss; $t_0 = 10^{-14}$ sec; $\rho = 10^{4}$ cgsm = 10^{-5} ohm-cm.

H	ρ	R/ρ	c	t_0
		Ag, Silver		
5 to 7*	0.15†	− 0.59†	− 0.206	− 2.3
5 to 7		(2)	− 0.44	− 5.0
		Bi,‡ Bismuth (37)		
0.80	14.1	−109	−109	−1232
2.45	15.4	− 64.9	− 65	− 734
6.15	17.7	− 44.3	− 44.2	− 500
9.75	20.5	− 31.2	− 31.2	− 352
11.10	21.1	− 29.1	− 29.2	− 330
12.85	22.5	− 26.3	− 26.3	− 298
7.70*	11†	− 92†	− 74	− 840
0.1		(2)	− 72.2	− 820
		C, Graphite (37)		
2.60	9.95	− 6.15	− 6.15	− 69.4
4.20	10.95	− 6.05	− 6.05	− 68.4
6.55	13.8	− 5.51	− 5.52	− 62.4
8.40	16.5	− 4.91	− 4.90	− 55.4
9.90	19.4	− 4.59	− 4.60	− 52.0
11.30	21.8	− 4.34	− 4.32	− 48.8
4.6*	45†	− 1.5†	− 0.574	− 6.5
		Sb, Antimony		
4*	3.7†	+ 5.2†	+ 3.91	+ 44.2
1.8		(2)	+ 3.6	+ 40.7
		Te, Tellurium (71)		
1 to 9	15000†	+ 3.5†	+ 1.48	+ 16.6
		W, Tungsten (71)		
4	0.62†	+ 0.19†	+ 0.156	+ 1.8

TABLE 8.—(*Continued*)

H	ρ†	R/c	c	t_0
		Cu,‡ Copper (37)		
5 to 15	0.17	0.156	− 0.273	− 3.1
		Ni, Nickel (17)		
1	1.0	1.81	− 0.83	− 9.4
2		1.36	− 1.07	− 12.1
3		1.38	− 1.08	− 12.2
4		1.44	− 1.09	− 12.3
5		1.45	− 1.10	− 12.4
6		1.54	− 1.08	− 12.2
7		1.39	− 1.02	− 11.5
8		1.35	− 0.94	− 10.6
9		1.36	− 0.84	− 9.4
		Zn,‡ Zinc (37)		
10 to 17	0.57	0.569	+ 0.117	+ 1.32

* Data on this line are from (71).

† Not for same specimen as c.

‡ The above values of t_0 for Bi, Cu, and Zn are twice those given by Heaps (37). He computed t_0 from the relation $c = et_0/m$, while the above values are calculated from the Adams ([1, 2]) equation $c = et_0/2m$.

TABLE 9.—ETTINGSHAUSEN EFFECT (P)

$P = A \times 10^{-n}$; t = temperature, in °C; t_R denotes room temperature; unit of H = 1000 cgsm = 1 kilogauss; P = 1 cgsm = 0.1°C-cm/ampere-gauss.

	t	H	A	n	Lit.
Ag	t_R	*	− 1.65	9	(74, 75)
Al	t_R	*	+ 1.06	9	(74, 75)
As	20	4 to 8	+ 1.75	7	(46)
Au	25	9.3	− 1.1	9	(34)
	55	9.3	− 0.6	9	(34)
Bi	15	4.71	+ 5.8	5	(22)
	14	10.00	+ 10	5	(5)
	18	6.29	+ 5.16	5	(79)
	18	6.29	+ 5.81	5	(79)
	44	0.3 to 1.2	+ 3.31	5	(62)
	23	3 to 14	+ 7.34	5	(68)
C	90	10.27	+ 5	6	(79, 80)
C†	17	5.46	− 59.8	6	(28)
	90	5.46	− 54.6	6	(28)
Cd	t_R	*	− 2.87	9	(74, 75)
Co	24	4.4	+ 9	9	(79, 80)
	t_R	*	+ 21.6	9	(74, 75)
	25	9.3	+ 8.7	8	(34)
	45	9.3	+ 10.6	8	(34)
Cu	t_R	*	− 1.6	9	(74, 75)
Fe	18	6.29	− 57	9	(79)
	12.2	5.00	− 49.2	9	(35)
	83.9	5.00	− 61.2	9	(35)
	t_R	*	− 42.6	9	(74, 75)
Steel	20	*	− 67	9	(79, 80)
Ni	18	10.62	+ 28	9	(80)
	18	6.29	+176	9	(79)
	t_R	*	+ 30.3	9	(74, 7
	37.5	9.3	+ 79.2	9	(34)
	57.5	9.3	+107	9	(34)
	77.5	9.3	+142	9	(34)
Pd	25	9.3	+ 17.3	9	(34)
	45	9.3	+ 19.1	9	(34)
	65	9.3	+ 22.5	9	(34)
Sb	18	*	+ 1.94	6	(79)
	20	9.13	+ 2	6	(5)
Si	18.7	6.15	+ 2.65	3	(28)
	89.7	6.15	+ 1.72	3	(28)
	60	*	<+ 3	6	(13)

TABLE 9.—(*Continued*)

	t	H	A	n	Lit.
Te.....	65	5.5	+ 0.14	3	(47)
	65	5.5	+ 0.29	3	(47)
	13	1 to 15	+ 7.19	5	(77)
	27	1 to 15	+ 10.45	5	(77)
	79	1 to 15	+ 25.6	5	(77)
	124	1 to 15	+ 36.1	5	(77)
Zn.....	t_R	*	− 2.67	9	(74, 75)
		Heusler alloy			
	t_R	*	< 3	8	(81)
		Molybdenite			
	18.1	5.46	+ 27.7	3	(28)
	91.3	5.46	+ 6.98	3	(28)

* Magnetic field not stated by observer. † Graphite.

TABLE 10.—NERNST EFFECT (Q): ELEMENTARY SUBSTANCES

$Q = A \times 10^{-n}$; t = temperature, in °C; t_R denotes room temperature; unit of H = 1000 cgsm = 1 kilogauss; Q = 1 cgsm = 10^{-8} volt/gauss-°C.

	t	H	A	n	Lit.
Ag.....	18	*	− 43	5	(79, 80)
		*	− 18	5	(74, 75)
Al.....	40	22.7	+ 39	6	(74, 75)
	55	*	− 20	6	(81)
As.....	20	4 to 8	+225	5	(46)
Au.....	25	9.3	−181	6	(34)
	55	9.3	−181	6	(34)
Bi†.....	18	10.57	+275	3	(79)
	27.5	9.92	+136	3	(47)
	42	10.00	+184	3	(5)
	57	2.50	+132	3	(52)
Cd.....		*	− 12	5	(74, 75)
Ce.....	60	17.5	+ 10	5	(68)
Co†.....	18	6.29	+ 20	4	(79)
	27	10.0	+ 18	4	(68)
	57	2.10	+ 25.4	4	(52)
	60	17.5	+ 20.0	4	(68)
		*	+ 7.8	4	(74, 75)
	25	9.3	+ 19.0	4	(34)
	45	9.3	+ 21.7	4	(34)
Cu.....	18	*	− 27	5	(80)
	43.0	13.5	− 16.7	5	(74, 75)
	57	13.3	− 9.0	5	(52)
Fe.....	57	10.1	−156	5	(52)
	48	10.8	− 87	5	(14)
	55	6.29	−105	5	(79)
	55	*	−166‡	5	(80)
	31	5.55	− 86.0	5	(35)
	60	5.55	− 98.0	5	(35)
	60	17.5	− 81.0	5	(68)
	48.6	14.8	−106	5	(74, 75)
In.....	60	17.5	+ 32	6	(68)
Ir.....	18	*	− 5	6	(80)
	18	*	> − 2	6	(80)
Li.....	60	17.5	+160	6	(68)
Mn.....		*	+ 15	6	(81)
Mo.....	60	17.5	−172	6	(68)
Ni§.....	55	10.62	+ 13	4	(79)
	55	6.29	+ 35.5	4	(79)
	27	2.0	+ 52.5	4	(68)
	37	1.70	+ 38	4	(50)
	43	4.20	+ 29.5	4	(74, 75)
	37.5	9.3	+ 24.8	4	(34)

TABLE 10.—(*Continued*)

	t	H	A	n	Lit.
Ni§.—	57.5	9.3	+ 29.2	4	(34)
(*Cont'd*)	77.5	9.3	+ 35.2	4	(34)
Pb.....	57	*	− 5	6	(52)
Pd.....	18	*	+127	6	(80)
	18	*	+ 51	6	(80)
	25	9.3	+327	6	(34)
	45	9.3	+326	6	(34)
	65	9.3	+334	6	(34)
Sb.....	18	*	+176	4	(79)
	44	9.13	+147	4	(5)
	57	1.7	+ 88.7	4	(52)
Si.....	47.4	5.80	+ 33.3	3	(28)
	50	10 to 20	+ 20	3	(13)
	50	10 to 20	+ 11.3	3	(13)
Sn.....	57	*	− 4(?)	6	(52)
Ta.....	60	17.5	+ 98	6	(68)
Te.....	33	3.00	+ 36	2	(47)
	45.8	4.34	+ 28.7	2	(77)
	204	4.33	+ 26.8	2	(77)
Tl.....	60	17.5	− 37	6	(68)
W.....	60	17.5	−100	5	(68)
Zn.....	46.4	13.5	− 73	6	(74, 75)
	57	13.8	− 54	6	(52)
	18	*	−240	6	(80)

* Magnetic field not stated by observer. † *See also* Table 12. ‡ Steel. § *See also* Fig. 6.

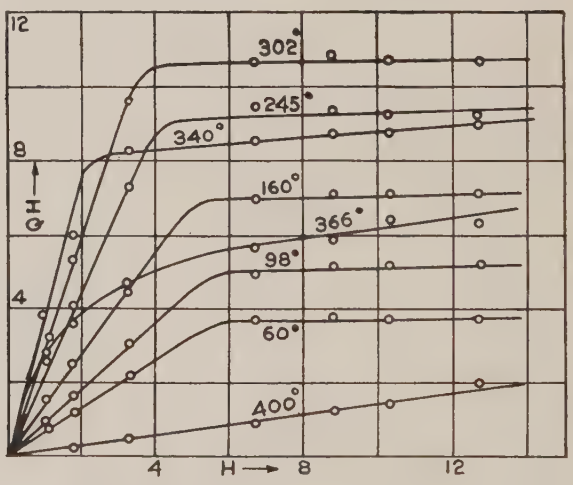

FIG. 6.—Nernst effect (Q) in nickel (65). Unit of QH is undetermined, of H = 1 kilogauss; temperatures are °C; *see also* Tables 10, 12.

TABLE 11.—NERNST EFFECT (Q): ALLOYS

$Q = A \times 10^{-n}$; C_2 = concentration of constituent 2; t = temperature, in °C. Unit of C_2 = 1 % by weight; H = 1000 cgsm = 1 kilogauss; Q = 1 cgsm = 10^{-8} volt/gauss-°C.

	C_2	A	n
(1) Fe, Iron	0	− 9.75	4
	1.07	− 4.21	4
(2) Ni,	1.93	− 3.06	4
Nickel (69)	7.05	+ 19.03	4
	10.20	+ 38.0	4
	13.11	+ 49.5	4
	56.0	+ 1.33	4

	C_2	A	n
(1) Ni,	0	+ 34.8	4
Nickel	5	+118	4
	7.5	+147	4
	10	+207	4
(2) Cu,	15	+256	4
Copper (69)	25	+350	4
	30	+174	4
	35	+ 9.7	4
	50	+ 1.7	4

TABLE 11.—(*Continued*)

Heusler Alloy (81)
25Mn + 15Al + 60Cu

t	H	A	n
55	3.40	+ 57	5
55	5.10	+ 48	5

Monel (67)
68Ni + 29.5Cu + 1.5Fe + 1Mn

60	1.50	+323	3

Nichrome (67)

t	H	A	n
43	2.50	+708	4

Steel (79)

55	*	−166	5

* Value of H is not stated.

TABLE 12.—NERNST EFFECT (Q): VARIATION WITH TEMPERATURE

Unit of Q = 0.001 cgsm = 10^{-11} volt/gauss-°C; of H = 1 kilogauss; t = temperature, °C

	Ni*	Co
t	Q (66)	
27	+ 5.25	+ 1.80
77	+ 7.25	+ 2.15
127	+ 9.75	+ 2.70
177	+13	+ 3.30
227	+16.7	+ 4
277	+21.3	+ 4.85
327	+27.0	+ 5.70
377	+34.0	+ 6.75
427	+ 2	+ 7.80
477		+ 8.90
527		+10

Bi (78); H = 6

t	Q
−119	+900
− 30.5	+380
+ 10.0	+173
+ 62.0	+ 46

Sb (5); H = 10

− 75	+ 21.8
− 19	+ 19.8
+ 39	+ 14.8

* *See also* Fig. 6.

TABLE 13.—RIGHI-LEDUC EFFECT (S): ELEMENTARY SUBSTANCES

Unit of H = 1000 cgsm = 1 kilogauss; S = 10^{-7} cgsm = 10^{-7} gauss^{-1}; t = temperature, °C

	t	H	S	Lit.
Ag	t_R	*	− 4.04	(80)
		5.2	− 2.7	(74, 75)
Al	40	22.7	− 0.63	(74, 75)
As	20	4 to 8	+ 4.15	(46)
Au	25	9.3	− 3.00	(34)
	55	9.3	− 2.64	(34)
Bi	18	3.93	−20.5	(79)
	18	6.29	+17.4	(79)
	34	6.10	−16	(23)
	42	10.00	+11	(5)
	43.3	0.3 to 1.2	−23	(63)
	52	10.90	−40.5	(70)
Cd	60.5	12.20	+ 1.1	(70)
		*	+ 0.89	(74, 75)
Co	t_R	10.57	+ 1.3	(79)
		*	+ 1.1	(74, 75)
	25	9.3	+ 3.76	(34)
	45	9.3	+ 4.25	(34)
Cu	t_R	*	− 1.4	(79)
	t_R	*	− 2.32	(80)
	43.9	21.40	− 2.27	(74, 75)
Fe	48	7.30	+ 6.08†	(14)
	44	6.50	+ 4.29	(35)
	60.2	5.50	+ 6.32	(35)
	t_R	6.29	+ 3.9	(79)
	t_R	*	+ 6.87‡	(80)
	48.6	11.30	+ 5.54	(74, 75)
	56.9	11.90	+ 3.92§	(70)
Ir	t_R	*	+ 0.55	(80)
	t_R	*	+ 0.41	(80)

TABLE 13.—(*Continued*)

	t	H	S	Lit.
Mo	57.5	12.30	+ 1.75	(70)
Ni	t_R	10.62	− 2.0§	(79)
	t_R	6.29	− 5.5§	(79)
	61	10.88	− 6.15	(70)
	61.5	8.50	− 5.30	(74, 75)
	37.5	9.3	− 5.28	(34)
	57.5	9.3	− 4.93	(34)
	77.5	9.3	− 4.46	(34)
Pd	t_R	*	− 0.33	(80)
	t_R	*	− 0.18	(80)
	25	9.3	− 0.487	(34)
	45	9.3	− 0.414	(34)
	65	9.3	− 0.380	(34)
Pt	t_R	*	− 0.21	(80)
Sb	18	*	+20.1	(79)
	20	9.13	+20	(5)
	56.7	11.00	+26.2	(70)
Si	47.8	5.00	+ 2.5	(28)
	47.4	5.80	+ 2.97	(28)
Te	34	5.2	+40	(47)
	114	7.75	+62	(77)
W	58.6	10.90	+ 1.5	(70)
Zn	46.4	21.10	+ 1.06	(74, 75)
	t_R	*	+ 1.29	(80)
	58.5	10.9	+ 1.24	(70)

* Magnetic field not stated by observer. † Soft. ‡ Steel. § Electrolytic.

TABLE 14.—RIGHI-LEDUC EFFECT (S): ALLOYS

Unit of C_1 = 1 % of constituent 1; S = 10^{-7} cgsm = 10^{-7} gauss^{-1}; of H = 1 kilogauss

	C_1	S
(1) Bi, Bismuth	0	+26.2
	10	+13.2
	20	+ 9.5
(2) Sb, Antimony (70); H = 11	30	+ 0.95
	39	− 6.0
	50	−15.4
	60	−19.5
	70	−35.4
	91	−37.5
	100	−40.5
Steel, $t = t_R$, H = *		+ 6.87

* Value not stated by observer.

	C_1	S
(1) Sb, Antimony	0	+ 1.24
	16	+ 0.660
	30	+ 0.840
(2) Zn, Zinc (70); H = 11	40	+ 0.677
	50	+ 0.850
	60	+ 0.908
	70	+ 2.09
	80	+ 2.75
	84	+ 3.20
	90	+ 4.27
	100	+26.2
Nichrome, t = 59.3°C		+ 3.88†

† H = 10.8 kilogauss.

TABLE 15.—INCREASE (Δr) PRODUCED IN ELECTRIC RESISTANCE (r) BY MAGNETIC FIELD (H): NON-MAGNETIC MATERIALS

$\Delta r/r = CH^2$; $C = A \times 10^{-n}$; ‖ denotes that H is parallel to the current; for unmarked values, H is perpendicular to the current; unit of C = 1 cgsm = 1 gauss^{-2}; of H = 1 cgsm = 1 gauss; t = temperature, °C.

Ag, Silver*

t	A	n	Lit.
22	25	14	(58, 60)
22	37	14	(29)
23	18‖	14	(58, 60)

Au, Gold*

23	36	14	(29, 36, 58)
100	30	14	(53)
24	22	14	(53)

Au.—(*Continued*)

t	A	n	Lit.
−253	17†	11	(56)
23	32‖	14	(36)
22	12‖	14	(53)

Bi, Bismuth; *cf.* Tables 16, 17

t_R	75‖	10	(5)

TABLE 15.—(*Continued*)

C, Carbon‡

t	A	n	Lit.
t_R	44§	14	(58)
16	78¶	12	(43)
−186	225¶	12	(43)

Cd, Cadmium

22	27	13	(29, 36, 59)
98	99	14	(43)
55	160	14	(43)
16	265	14	(43)
−186	51†	12	(43)
−253	76†	10	(57)
17	177‖	14	(36)
−253	50‖†	10	(57)

Cu, Copper**

22	27	14	(29, 58, 60)
100	55	14	(53)
21	27	14	(53)
−253	14†	10	(56)
−258	10†	10	(56)
t_R	33‖	14	(58)
23	22‖	14	(60)
21	35‖	14	(53)
100	65‖	14	(53)

Hg, Mercury

20	54	14	(58)
−253	15	12	(57)
−258.5	60	12	(57)

Pb, Lead

22	52	15	(29)
−253	55†	12	(57)
−253	55‖†	12	(57)

Pd, Palladium

25	11	14	(29)
−253	15†	12	(56)

Pt, Platinum

t_R	53.7	15	(58)
22	39	15	(29)

Sb, Antimony; *see* Table 17

Si, Silicon

t_R	26	13	(42)

Sn, Tin

22	23	14	(29, 58)
−253	92†	11	(57)
t_R	18‖	14	(58)
−253	92‖†	11	(57)

Ta, Tantalum

25	30	15	(29)

Te, Tellurium

t_R	1 to 10	11	(7, 9, 36, 45, 48)
24	277‖	13	(36)

Zn, Zinc*

t	A	n	Lit.
t_R	8	13	(29, 58)
20	14	13	(36)
55	54	14	(43)
18	85	14	(43)
−186	17	12	(43)
t_R	60‖	14	(58)
20	82‖	14	(36)

FeS_2, Pyrite

22	< 2	13	(36)

MoS_2, Molybdenite

22	− 37	13	(36)

PbS, Galena

22	2††	12	(36)
22	236	14	(36)

Pt, Ir, Platinum-iridium

100	+ 10	14	(53)
−183	− 25	15	(53)

Cu, Ni, Advance

23	− 12	14	(60)
23	− 12‖	14	(60)

Cu, Ni, Mn, Constantan‡‡

79	+ 32	15	(53)
16.7	− 23	14	(53)
−183	− 51	12	(53)
84	− 13‖	14	(53)
19	− 26‖	14	(53)
−183	− 49‖	12	(53)

Cu, Ni, Mn, Eureka††

100	− 8	14	(53)
26	− 14	14	(53)
100	− 8‖	14	(53)
25	− 18‖	14	(53)

Cu, Ni, Mn, Manganin‡‡

23	− 90	15	(60)
100	− 35	14	(53)
20	− 55	15	(53)
−183	− 27	13	(53)
23	− 87‖	15	(60)
100	− 3‖	14	(53)
5	− 6‖	14	(53)
−183	− 24‖	13	(53)

Cu, Ni, Mn, Platinoid‡‡

24	− 9	14	(53)
100	− 2	14	(53)
25	− 87‖	15	(53)

Cu, Sn, P, Phosphor bronze

27.5	− 5	15	(53)
100	+ 1	13	(53)
−183	+ 5	14	(53)

Ni, Cr, Mn, Fe, Nichrome‡‡

28.5	−114	14	(53)
27	+ 18‖	14	(53)

* Brown (12.1) found $\Delta r/r \pm$ <0.0001 for $H \gtrless 10^4$, whether ‖ or ⊥. For Zn he found same values for single crystal. †† A varies with H; for Cd, H = 7 600; for Pb and Sn, H = 11 000. ‡ *See also* Table 18. § H = 22 000. ¶ H = 3 300; for graphite at 15.5°C, A = 77.5. **Brown (12.1) found $\Delta r/r$ = 0.0004 for $H = 10^4$ and ‖; $\Delta r/r \pm$ <0.0001 for $H \gtrless$ 8000 and ⊥. †† Ranges from 0.05 to 4.5. ‡‡ Constantan = 55.86 Cu, 43.33 Ni, 0.66 Mn, trace Fe; eureka = 53.53 Cu, 44.63 Ni, 0.96 Mn, 0.71 Fe; manganin = 82.3 Cu, 4.0 Ni, 12.3 Mn, 0.08 Fe; platinoid = 54.21 Cu, 43.91 Ni, 1.02 Mn, 0.52 Fe; nichrome = 15.57 Cr, 58.31 Ni, 3.19 Mn, 22.42 Fe.

TABLE 16.—INCREASE PRODUCED IN ELECTRICAL RESISTANCE (r) OF BISMUTH BY TRANSVERSE MAGNETIC FIELD (H)

Tabular values are $A = \frac{r - r_0}{r_0}$, r_0 = resistance when field = 0; r and r_0 refer to the same temperature; H is perpendicular to direction of current; *see also* Tables 15, 17; unit of H = 1000 cgsm = 1 kilogauss.

Wire of Electrolytic Bismuth (10)

H \ t	183°	100°	60°	18°	0°C
4	0.017	0.03	0.05	0.12	0.18
8	0.045	0.10	0.17	0.32	0.43
12	0.072	0.18	0.30	0.52	0.71
16	0.095	0.27	0.43	0.79	1.02
20	0.13	0.37	0.58	1.04	1.33
25	0.17	0.48	0.78	1.33	1.73
30	0.21	0.61	0.97	1.65	2.17
35	0.26	0.73	1.13	2.01	2.62

H \ t	−37°	−100°	−135°	−192°C
4	0.25	0.71	1.25	4.80
8	0.70	1.85	3.80	13.7
12	1.20	3.04	6.83	26.0
16	1.70	4.87	10.6	37.0
20	2.18	6.71	17.2	48.5
25	2.98	9.57	21.1	62.7
30	3.77	13.0	29.3	78.2
35	4.62	16.4	32.9	87.7

Wire of Electrolytic Bismuth (56)

H \ t	17°	−103°	−133.5°	−183.5°C
2.76	0.078	0.506	0.884	2.65
5.54	0.211	1.328	2.236	7.60
7.37	0.313	1.893	3.321	12.21
9.20	0.414	2.576	4.574	17.37
11.85	0.557	3.649	6.745	26.76
13.60	0.652	4.626	8.231	34.93
15.67	0.767	5.500	10.37	43.74
17.08		6.268	12.04	50.95

H \ t	−201°	−252.7°	−258°C
2.76	3.36	18.5	
5.54	10.43	54.8	65.3
7.37	16.79	92.0	105.5
9.20	23.75	129.7	152.9
11.85	37.35	190.6	220.8
13.60	47.9	239.5	271.0
15.67	61.6	291.3	333.5
17.08	71.4	333.1	379

Bismuth Plate (26)

100°		11.5°		−23°		−90°		−182°C	
H	A	H	A	H	A	H	A	H	A
2.2	0.009	1.05	0.009	1.06	0.015	1.02	0.035	2.05	0.359
3.95	0.026	2.06	0.030	2.14	0.052	2.14	0.125	3.73	0.902
4.83	0.040	3.06	0.58	3.11	0.097	3.10	0.224	4.74	1.271
6.10	0.058	4.43	0.104	3.79	0.132	3.76	0.299	6.00	1.757
		6.03	0.166	4.41	0.166	4.15	0.346		
				5.25	0.215	5.20	0.477		
				6.05	0.265	6.11	0.596		

TABLE 16.—(*Continued*)

Bismuth Crystal (48); $H \perp$ axis

H	Current ∥ axis			Current ⊥ axis		
	22.5°	−79°	−186°C	14°	−79°	−186°C
2.12	0.050	0.225	0.335	0.039	0.096	0.061
3.12	0.092	0.377	0.442	0.073	0.142	0.097
3.50	0.121	0.431	0.474	0.086	0.157	0.106
4.98	0.198	0.621	0.565	0.143	0.215	0.114

TABLE 17.—ELECTRICAL RESISTANCE (r) OF ANTIMONY AND OF BISMUTH IN TRANSVERSE MAGNETIC FIELD (H) (30)

$r/r_0 = a\{1 - b(c - dH)\}$; $r/r_{00} = \alpha\{1 - \beta(\gamma - \delta H)\}$ where r_0 = resistance at t°C when $H = 0$; r_{00} = resistance at 0°C when $H = 0$; unit of H = 1000 cgsm = 1 kilogauss.

Bismuth* (compressed powder)

t	α	β	γ	δ
−183	102.34	0.998	85.99	2.04
−201	134.06	0.999	86.64	2.166
−253	75.74	1.005	82.97	5.09
−258	68.4	1.005	82.03	5.45

Antimony† (crystal)

t	a	b	c	d
18	1.519‡	0.336	91.13	1.125
−188	2.742‡	0.656	77.95	2.022
18	1.167§	0.1453	79.95	2.665
−188	10.08§	0.0957	80.88	1.069

* *See also* Tables 15, 16. † Current perpendicular to axis. ‡ Field parallel to axis. § Field perpendicular to axis.

TABLE 18.—ELECTRICAL RESISTANCE (r) OF GRAPHITE IN TRANSVERSE MAGNETIC FIELD (H) (59)

Current perpendicular to axis of crystal; $r/r_{00} = a + bH^{1.745}$; r_{00} = resistance at 0°C when $H = 0$; $A = \dfrac{r - r_0}{r_0}$; r_0 = resistance at t°C when $H = 0$; unit of H = 1000 cgsm = 1 kilogauss; *see also* Table 15.

No.	a*	b*	H	A†	A‡	H	A†	A‡
I	1.01	0.0171	5.73	0.40	0.008	26.15	5.91	0.115
II	1.01	0.0205	9.60	1.04	0.020	29.75	7.36	0.148
III	1.004	0.0160	14.78	2.16	0.040	33.98	9.28	0.172
IV	1.014	0.0188	20.3	3.91	0.070	35.2	9.89	0.189
V	1.02	0.0214	21.9	4.56	0.083	36.4	10.5	0.194
Temperature = 18°C			23.2	4.75	0.092	Temperature = 20°C		

* Cleavage plane normal to H. † Axis of crystal parallel to H. ‡ Axis of crystal normal to H.

TABLE 19.—INCREASE (Δr) PRODUCED IN ELECTRICAL RESISTANCE (r) BY TRANSVERSE MAGNETIC FIELD (H): MAGNETIC MATERIALS

$\dfrac{\Delta r}{r} = 0.0001A$; for effect of longitudinal field, *see* Table 20; unit of H = 1000 cgsm = 1 kilogauss; t = temperature, °C

Co, Cobalt (6)

H	A	H	A
2.4	− 3.64	10.3	−47.44
5.1	− 9.28	11.7	−60.82
6.0	−17.56	13.8	−64.40
8.5	−24.58	16.16	−67.96
(29)			
3.8	− 5.89	11.4	−56.9
8.2	−42.3	16.16	−69.9

Fe, Iron (12.1)

H	A	H	A
4	±<1	8	±<1
(29)			
0.22	−0.387	3.40	−0.851
0.47	−0.381	8.44	−1.630
1.33	−0.481	11.48	−3.893

TABLE 19.—(*Continued*)

Fe (9, 56)

t =	15°	−252.8°	−258.6°C
H	A		
0.99	+2.8		−1.7
1.50	+3.8	−2.0	
2.52	+5.7	−2.9	−2.6*
3.75	+6.0	−2.7	−3.1
4.94	+5.4	−2.2	−2.4
6.11	+3.2	−0.9	−1.4
7.26	+0.6	+0.7	+0.3
8.25	−2.1†	+2.6	+2.6
9.065	−4.7	+3.6	+3.6
9.75		+4.6	+4.7
10.27	−9.1	+5.2	+5.4

* H = 2.50.
† H = 8.26.

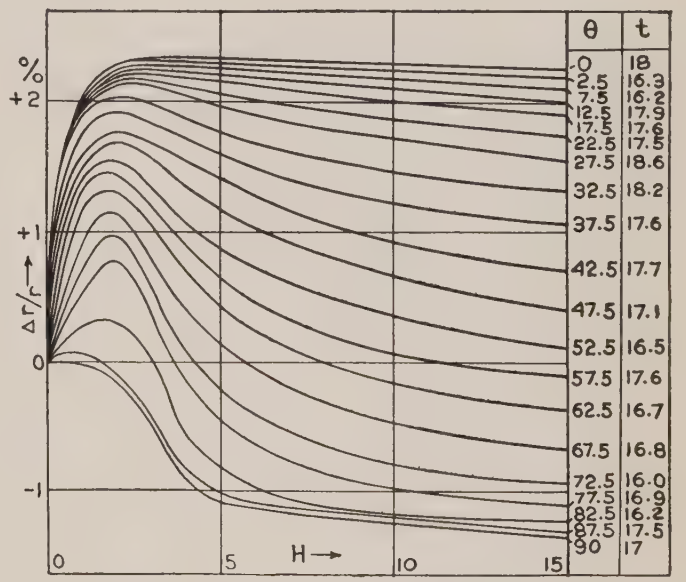

FIG. 7.—Effect of magnetic field (H) upon electrical resistivity (r) of nickel (40). Unit of H = 1 kilogauss; θ = angle direction of current makes with H; t = centigrade temperature; *see also* Tables 19, 20.

Ni, Nickel‡ (10)

t =	182°	100°	18°	0°	−75°	−190°C
H	A					
1	4	96	7	7	23	20
2	− 7	72	3	3	16	17
3	− 60	− 14	− 36	− 34	− 5	0
4	−115	− 70	− 72	− 60	−15	−17
6	−153	−102	− 83	− 70	−20	−19
8	−166	−115	− 90	− 76	−23	−19
10	−176	−123	− 95	− 82	−27	−18
12	−185	−130	−100	− 87	−30	−18
14	−195	−137	−104	− 91	−32	−18
16	−205	−144	−109	− 94	−35	−17
18	−215	−151	−113	− 98	−38	−17
20	−225	−159	−117	−103	−41	−16
25	−250	−176	−129	−112	−49	−14
30	−273	−195	−140	−122	−56	−12
35	−298	−213	−150	−132	−63	−10

‡ *See also* Fig. 7.

TABLE 19.—(*Continued*)

Ni, Nickel‡ (56)

t =	17.5°	−183°	−253°	−258.5°C
H	A			
1.75	5		10	
2.27		20		
2.50	5	30	20	
2.97	0			0
3.75	− 20	0	0	
4.95		− 55		
5.17	− 40			
5.64			− 80	− 70
6.14		− 65		
7.26	− 70			
8.25		− 95§	−120	−110
9.065	− 90		−130	
9.11		−125		
10.27	−110		−150	−130
10.40		−140		

‡ *See also* Fig. 7. § H = 8.29.

TABLE 20.—INCREASE (Δr) PRODUCED IN ELECTRICAL RESISTANCE (r) BY A LONGITUDINAL MAGNETIC FIELD (H): MAGNETIC MATERIALS

$\frac{\Delta r}{r} = 0.0001A$; for effect of transverse field, *see* Table 19; unit of H = 1000 cgsm = 1 kilogauss

Fe* (12.1)

H	A
10	+20

Ni†

23°C (36)

0.25	+125
0.50	195
0.75	220
1.00	230
1.25	233
1.50	235
1.75	236
2.00	237

* Induction = 36 000 cgsm. † *See also* Fig. 7. ‡ Electrolytic iron.

Ni.—(*Continued*)

H	A
18°C (39)	
0.15	+ 60
0.30	98
0.48	120
0.60	126
0.90	129
1.20	130
1.50	131
1.80	131

Norway Iron (36)

23°C

0.25	−15.0
0.50	−22.5
0.75	−26.0
1.00	−27.5

Norway Iron.—(*Continued*)

H	A
1.25	−27.8
1.50	−28.0
1.75	−28.0
2.00	−28.0

Fe‡ (38)

Room temp.

0.20	−15.5
0.40	−24.5
0.60	−29.0
0.80	−31.2
1.00	−31.7
1.20	−31.9
1.40	−32.0
1.60	−32.1

TABLE 21.—INCREASE (Δk) PRODUCED IN THERMAL CONDUCTIVITY (k) BY MAGNETIC FIELD (H)

$\Delta k = k_H - k_0$; k_H, k_0 = thermal conductivity in field H, in field = 0; as applied to H, $\perp$ [$\parallel$] indicate that H is perpendicular [parallel] to direction of flow of heat; $\Delta k/k = 0.001A$; unit of H =1 kilogauss.

	H	A	Lit.
Ag	10$\parallel$	±<0.4	(12.1)
	4 & 8$\perp$	±<0.4	(12.1)
Au	10$\parallel$	±<0.4	(12.1)
	4 & 8$\perp$	±<0.4	(12.1)
Bi*	3.5$\perp$	−>5	(11)
	6.0$\perp$	−58	(24)
	7.8$\perp$	−57	(44)
	9.0$\perp$	−21 to −52	(19)
	5.4$\perp$	−32	(76)

TABLE 21.—(*Continued*)

	H	A	Lit.
Cu	10$\parallel$	−2.3	(12.1)
	8$\parallel$	−2.1	(12.1)
	4 & 8$\perp$	±<0.4	(12.1)
Fe	10$\parallel$†	−11.4	(12.1)
	8$\perp$	±<0.4	(12.1)
	4$\perp$	−4	(12.1)
	16$\parallel$‡	−105	(11)
	7.8$\perp$	−10	(11)
	7.5$\perp$	−33¶	(11)
	1.7$\parallel$§	−small	(12)
	1.5$\parallel$§	−small¶	(12)
	0.051$\parallel$	−40¶	(12)
Ni	1.2§	**	(61)
Te	6.6$\perp$	−190	(77)
	4.7$\perp$	−100	(47)
Zn††	10$\parallel$	±<0.4	(12.1)
	8$\perp$	±<0.4	(12.1)

* Crystalline, but not single crystal. $\frac{k \perp \text{axis of crystal}}{k \parallel \text{axis of crystal}} = 1.42$ if $H = 0$, = 1.80 if $H = 4.9$ (49). † Induction = 36 000 cgsm. ‡ Induction. § Intensity of magnetization. ¶ Steel. $**\frac{k_H,\ H\parallel}{k_H,\ H\perp} = 1.05$ (61). †† Same for single crystal.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Adams, *3*, **27**: 244; 14. *241*, **53**: 47; 15. (2) Adams and Chapman, *3*, **28**: 692; 14. (3) Alterthum, *8*, **39**: 933; 12. **40**: 491; 13. (4) van Aubel, *34*, **135**: 786; 02. (5) Barlow, *8*, **12**: 897; 03. (6) Beattie, *3*, **45**: 243; 98. (7) Beckman, *64P*, **15**: 649; 12. *168*, Nos. **130a, 130b**; 12. (8) Beckman, *64P*, **15**: 988; 13. *168*, No. **132c**; 13. (9) Beckman, *8*, **54**: 182; 17.

(10) Blake, *88*, **9**: 294; 07. *8*, **28**: 449; 09. (11) Blyth, *3*, **5**: 529; 03. (12) Bordoni, *59*, **20**: 159; 10. (12.1) Brown, *2*, **32**: 508; 28. (13) Buckley, *2*, **4**: 482; 14. (14) Campbell, *2*, **26**: 416; 08. (15) Campbell, *Galvanometric and thermomagnetic effects*. New York, Longmans, 1923. (16) Caswell, *2*, **20**: 280; 22. (17) Chapman, *3*, **32**: 303; 16. (18) Corbino, *59*, **1**: 397; 11. (19) Ettingshausen, *8*, **33**: 129; 88.

(20) Ettingshausen and Nernst, *75*, **94 II**: 560; 86. *8*, **29**: 343; 86. (21) Ettingshausen and Nernst, *17*, **23**: 114, 176; 86. *8*, **31**: 760; 87. (22) Ettingshausen and Nernst, *8*, **33**: 474; 88. (23) van Everdingen, *64P*, **1**: 72; 99. *168*, No. **42**; 98. (24) van Everdingen, *64P*, **1**: 404; 99. *168*, No. **48**; 99. (25) van Everdingen, *64P*, **2**: 229; 00. *168*, No. **53**; 00. (26) van Everdingen, *64P*, **3**: 177; 01. *168*, No. **58**; 01. (27) Frey, *8*, **46**: 1057; 15. (28) Gottstein, *8*, **43**: 1079; 14. (29) Grunmach and Weidert, *63*, **7**: 729; 06. *8*, **22**: 141; 07.

(30) de Haas, *64P*, **16**: 1110; 14. (31) Hall, *339*, **2**: 287; 79. *12*, **19**: 200; 80. (32) Hall, *12*, **20**: 161; 80. **25**: 215; 83. **36**: 131, 277; 88. *3*, **12**: 157; 81. (33) Hall, *12*, **29**: 117; 85. (34) Hall, *197*, **11**: 416; 25. *2*, **26**: 820; 25. (35) Hall and Campbell, *65*, **46**: 623; 11. (36) Heaps, *3*, **22**: 900; 11. **24**: 813; 12. (37) Heaps, *2*, **11**: 340; 18. (38) Heising, *2*, **4**: 315; 14. (39) Jenkins, *3*, **27**: 731; 14.

(40) Jones and Malam, *3*, **27**: 649; 14. (41) Königsberger and Gottstein, *63*, **14**: 232; 13. (42) Königsberger and Gottstein, *8*, **46**: 446; 15. **47**: 566; 15. (43) Laws, *3*, **19**: 685; 10. (44) Leduc, *34*, **104**: 1783; 87. *51*, **6**: 378; 87. (45) Lenard, *8*, **39**: 619; 90. (46) Little, *2*, **28**: 418; 26. (47) Lloyd, *12*, **12**: 57; 01. (48) Lownds, *8*, **9**: 677; 02. (49) Lownds, *3*, **5**: 141; 03.

(50) Moreau, *51*, **9**: 497; 00. (51) Moreau, *34*, **130**: 122, 412, 562; 00. *51*, **10**: 478; 01. (52) Nernst, *8*, **31**: 760; 87. (53) Obata, *338*, No. **101**; 21. (54) Onnes, *64P*, **16**: 987; 14. *168*, No. **139f**; 14. (55) Onnes and Beckman, *64P*, **15**: 307, 319, 664; 12. *168*, Nos. **129a, 129c, 130c**; 12. (56) Onnes and Beckman, *64P*, **15**: 981, 997; 13. *168*, No. **132a**; 13. (57) Onnes and Hoff, *64P*, **17**: 520; 14. *168*, No. **142b**; 14. (58) Patterson, *3*, **3**: 643; 02. (59) Roberts, *3*, **26**: 158; 13. *8*, **40**: 453; 13.

(60) Sanders and Carman, *2*, **21**: 197; 23. (61) Schmaltz, *8*, **16**: 398; 05. (62) Senepa, *22*, **21**: 53; 12. *149*, **35**: 58; 13. (63) Senepa, *59*, **6**: 303; 13. (64) Smith, *2*, **30**: 1; 10. (65) Smith, *2*, **32**: 178; 11. (66) Smith *2*, **33**: 295; 11. (67) Smith, *2*, **1**: 339; 13. (68) Smith, *2*, **8**: 79; 16. (69) Smith, *2*, **17**: 23; 21.

(70) Smith and Smith, *2*, **5**: 35; 15. (71) Smith, *2*, **8**: 402; 16. (72) Steinberg, *8*, **35**: 1009; 11. (73) von Traubenberg, *8*, **17**: 78; 05. (74) Unwin, *68*, **34**: 208; 14. (75) Unwin, *68*, **41**: 44; 21. (76) Ward, *3*, **48**: 971; 24. (76.1) Webster, *201*, **23**: 800; 27. (77) Wold, *2*, **7**: 169; 16. (78) Yamaguchi, *8*, **1**: 214; 00. (79) Zahn, *8*, **14**: 886; 04.

(80) Zahn, *8*, **16**: 148; 05. (81) Zahn and Schmidt, *88*, **9**: 98; 07.

MAGNETO-OPTICS

A. Cotton, R. Lucas, and M. Cau

This section is devoted to data pertaining to the rotation of the plane of polarization of light (I) during transmission through materials and along a magnetic field (Faraday effect), and (II) at reflection from magnetized materials (Kerr effect) (p. 435). Other magneto-optic phenomena are considered elsewhere; consult the index.

I. ROTATION DURING TRANSMISSION—FARADAY EFFECT

A. Cotton and R. Lucas

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The *Verdet constant* (V) of a substance is $V = \alpha/(lH\cos\varphi)$, where α = angular rotation, l = length of path through the substance, H = intensity of magnetic field, and φ = angle between l and H. The positive direction of α is related to that of l as the rotation of a right-handed screw is related to its advance; V is positive when α is in the direction of the Amperian currents which would produce the field H. V_D and V_{Hg} are the values of V which correspond to the D lines and to the green mercury line (λ = 5461 Å), respectively.

The *specific magnetic rotatory power* is $[\omega] = V/d$, the *molecular magnetic rotatory power* is $M\,[\omega]$, where d = density, M = molecular weight. The ratios of $[\omega]$ and of $M\,[\omega]$ to the corresponding values for water at the same temperature and for the same λ, are called, respectively, the *relative specific* and the *relative molecular* ($[\Omega]$) magnetic rotatory powers with reference to water If the rotation depends upon the nature and the mass of material, per unit of area traversed, and not upon the closeness of packing of the molecules, then for a mixture $[\omega]_m = V/\alpha = \tau_1[\omega]_1 + \tau_2 \times [\omega]_2 + \cdots$, where τ_1, $\tau_2 \cdots$ are the titers of the several constituents. In general, this relation is not exactly satisfied. If $[\omega]$ for each of the pure constituents is known, it is convenient to express $[\omega]_m$ in terms of Δ defined by $[\omega]_m = (1 + \Delta)(\tau_1[\omega]_1 + \tau_2[\omega]_2 + \cdots)$. When $[\omega]_m$ is known for a binary mixture, but $[\omega]_2$ is not known, it is customary to call the quantity $[\omega]'_2$, defined by $\tau_2[\omega]'_2 = [\omega]_m - \tau_1[\omega]_1$, the specific magnetic rotatory power of that constituent; it is preferable to call it the apparent power under the stated conditions.

Table 1.—Verdet Constant for Water*

t = temperature, °C; λ_D = 5893 Å. Unit of V = 0.01′ per cm-gauss; λ = 1 Å

t	V_D†	λ	V/V_D†‡	λ	V/V_D†
0	1.311	3 034	4.6270	4 958	1.4520
20	1.308	3 303	3.7337	5 461	1.184§
30	1.306	3 611	2.9908	6 000	0.964‖
40	1.302	3 962	2.4051	8 000	0.535‖
60	1.294	4 341	1.9514	10 000	0.337‖
80	1.282	4 360	1.916§	12 500	0.222‖
90	1.274	4 678	1.6481		

* $\frac{c_1}{n\lambda^2}\left\{\left(\frac{\lambda^2}{\lambda^2-\lambda_1^2}\right)^2 + K_1\right\}$; λ_1 = 1260.4 Å, K_1 = 0.7381 (21). $V = \frac{c}{\lambda}(n - K\lambda\frac{dn}{d\lambda}$; K = 77.65, for visible spectrum only (14, 23).

† $V_t = V_{20}\{1 - 153(t - 20) \times 10^{-6} - 3.06(t - 20)^2 \times 10^{-6}\}$ if $3 \lesssim t \lesssim 98$; V_D, 20° = 1.308 (22).

‡ (21) except as noted.

§ (25).

‖ (13).

Table 2.—Verdet Constant for Gases and Vapors

For certain gases (26), $V = \frac{a}{\lambda} + \frac{b}{\lambda^3}$ if $0.423\mu \lesssim \lambda \lesssim 0.684\mu$.

For liquefied gases, *see* Tables 3, 5. Temperature (t) in °C; λ_D = 0.5893μ. Unit of $V = 10^{-6}$ minute of arc per cm-gauss; $\lambda = 1\mu = 10^4$ Å; $p = 10^6$ barye = $0.987A_n$.

	t	p	V_D	a	b	Lit.
H*.....	9.5	83.3	456	138.8	45.19	(26)
N.....	*ca.* 20	*ca.* 1	6.92			(3)
N.....	14	98.1	549	171.22	52.86	(26)
O*.....	*ca.* 20	*ca.* 1	31.39			(3)
O.....	7	98.1	555	272.2	19.15	(26)
N_2O.....	*ca.* 20	*ca.* 1	6.28			(3)
N_2O.....	10.9	30.9	241	75.85	22.95	(26)
SO_2.....	20	3.3	38.40			(5)
CO_2*.....	6.5	1.1	8.61	2.68	0.83	(26)
CS_2.....	70	0.98	23.49			(5)
C_2H_4.....	*ca.* 20	*ca.* 1	34.48			(3)
Air.....	*ca.* 20	*ca.* 1	6.83			(3)
Air.....	13	98.1	551	191.5	46.19	(26)

* For dispersion of V in ultra-violet, *see* Table 12.

TABLE 3.—VERDET CONSTANT FOR PURE INORGANIC LIQUIDS AND SOLIDS AND FOR MISCELLANEOUS MATERIALS

For values in infra-red, *see* Table 8; for gases and vapors, *see* Table 2

Unit of $V = 0.001'$ per cm-gauss; $\lambda_D = 5893$ Å; t = temperature, °C

	t	V_D	Lit.
C*	16	12.8	(2)
N_2	−195.5	4.15	(8)
O_2	−182.5	7.82	(8)
P†	33	132.6	(2)
S†	114	80.9	(2)
H_2O‡	0	13.11	(22)
HCl§	20	11.60	(25)
HBr	15	34.3	(18)
HI		51.3	(18)
SO_2	− 10	18	(8)
H_2SO_4‖	16	10.5	(4)
H_2SO_4¶	15	10.16	(25)
S_2Cl_2	16	41.8	(4)
N_2O**	− 92	5.54	(28)
HNO_3††	16	8.76	(4)
PCl_3	16	27.7	(4)
P_4S	16	110	(4)
$AsCl_3$	16	42.53	(4)
$SbCl_5$	16	70.4	(4)
CO_2	26	2.07	(8)
SiO_2‡‡	20	16.64	(7)
$SiCl_4$	16	18.9	(4)
$TiCl_2$	16	− 15.21	(4)
$TiCl_4$	*See* Table 4		
$SnCl_2$	16	44.0	(4)
$PbSiO_3$†	16	77.9	(4)
$PbB_2O_4.H_2O$	16	59	(4)
$ZnS(\beta)$§§	16	225	(4)
$MgAl_2O_4$‖‖	16	21.0	(6)
CaF_2¶¶	16	8.83	(4)
NaCl	16	35.85	(4)
$Na_2B_4O_7.10H_2O$	16	17.2	(4)
KCl***	16	28.58	(4)
Amber	19	− 9.60	(20)
Glass, Jena:†††			
S.179	18	16.1	(6)
O.1143	18	22.0	(6)
O.451	18	31.7	(6)
O.469	18	44.2	(6)
O.500	18	60.8	(6)
S.143	18	88.8	(6)

* Diamond. † Fused. ‡ *See also* Table 1. § $d_{20}^{20} = 0.8240$. ‖ $d_{15} = 1.854$ g cm^{-3}. ¶ $d_{15}^{15} = 1.83840$ ** Liquid at 1 atm. †† Fuming. ‡‡ Quartz; perpendicular to axis; *see also* p. 343. §§ Zinc blende, sphalerite. ‖‖ Spinel colored with chromium. ¶¶ Fluorite. *** Sylvite. ††† S.179 = Phosphate crown; O.1143 = barium crown; O.451 = light flint; O.469 and O.500 = heavy flint; S.143 = very heavy flint.

TABLE 4.—VERDET CONSTANT FOR $TiCl_4$ (29)

Unit of $V = 0.001'$ per cm-gauss; $\lambda = 1$ Å; temperature = 13.4°C

λ	V	λ	V	λ	V	λ	V	λ	V
4355	54.39	4623	40.54	4723	36.89	5086	27.05*	5601	18.30
4358	56.33*	4688	38.43	4805	34.68*	5097	26.43	5780	16.18*
4436	49.27	4694	37.78	4840	33.25	5245	23.43	5956	14.71
4495	46.87	4722	37.82*	4889	31.70	5461	20.23*	6452	10.83

* Temperature = 17.9°C.

TABLE 5.—VERDET CONSTANT FOR PURE ORGANIC LIQUIDS

For values in infra-red, *see* Table 8; for relative molecular magnetic rotatory power, *see* Table 9. Temperature (t) in °C

Unit of $V = 0.001'$ per cm-gauss; $\lambda_D = 5893$ Å

	Liquid	t	V_D	Lit.
CS_2*	Carbon disulfide	0	43.41	(4)
		15.6	42.4	(25)
		18.0	43.0	(8)
		20	42.26†	(5)
		34	41.1	(25)
CCl_4	Carbon tetrachloride	15	16.03	(25)
CH_3Cl	Methyl chloride	18	12.9	(8)
$C_2H_4O_2$	Acetic acid	15.2	10.35	(25)
		32.0	10.19	(25)
C_2H_6O	Ethyl alcohol	25.0	11.12‡	(31)
C_3H_6O	Acetone	15.1	11.09	(25)
		31.5	10.86	(25)
C_3H_8O	*n*-Propyl alcohol	17.3	11.81	(25)
		59.5	11.21	(25)
$C_4H_8O_2$	Isobutyric acid	15.3	11.35	(25)
		31.8	11.15	(25)
$C_4H_{10}O$	Isobutyl alcohol	16.1	12.66	(25)
		55.2	12.03	(25)
$C_5H_{10}O_2$	Isovaleric acid	15.0	12.08	(25)
		33.9	11.83	(25)
$C_6H_{10}O_5$	Dimethyl malate	15.3	11.8	(11)
$C_6H_{12}O_2$	Methyl valerate	17.0	11.8	(11)
$C_8H_{14}O_5$	Diethyl malate	15.3	12.4	(11)
$C_8H_{14}O_6$	Diethyl tartrate	15.2	12.3	(11)
$C_{10}H_{14}O$	Carvone	14.9	18.4	(11)
$C_{10}H_{16}$	Limonene	15.6	16.5	(11)
$C_{10}H_{16}$	Turpentine	15.8	15.7	(11)
$C_{10}H_{16}O$	Pulegone	14.9	16.4	(11)
$C_{10}H_{18}O$	Citronellal	16.4	15.1	(11)
$C_{10}H_{18}O$	Menthone	16.7	13.7	(11)
$C_{10}H_{18}O_6$	Dipropyl tartrate	15.4	12.6	(11)

* $[\Omega]_D = 10.751$, 15°C (18); $[\Omega]_{Hg} = 10.86$, $t = 20$°C (15).

† $V_t = V_{20}\{1 - 164(t - 20) \times 10^{-5} - 1.43(t - 20)^2 \times 10^{-5}\}$ if $0 \leq t \leq 40$.

‡ Assumes V_D for H_2O at 25° = 0.01307′ per cm-gauss.

TABLE 6.—VERDET CONSTANT FOR SOLUTIONS OF INORGANIC SUBSTANCES

For specific magnetic rotatory power, *see* Table 10; for infra-red, *see* Table 8

Unit of $V = 0.001'$ per cm-gauss; d = 1g-cm^{-3}

Temperatures (t) in °C; $\lambda_D = 5893$ Å

Solvent	Solute	d	t	V_D	Lit.
H_2O	HCl	1.0762	15	16.8	(18)
	HCl	1.0758	20	16.71	(25)
	HBr	1.2039	15	19.4	(18)
	HI	1.2966	15	25.8	(18)
	HNO_3	1.336	15	10.5	(18)
	$H_2SO_4 + 3H_2O$			12.2	(2)
	$H_2SO_4 + 3H_2O$	1.5507	15	12.18	(25)
	NH_4OH	0.8918		15.3	(18)
	$AgNO_3$			18.03	(2, 4)
	$Bi(NO_3)_3$			19.22	(2, 4)
	$CaCl_2$	1.1504	20	16.5	(12)
	Fe_2Cl_6*	1.6933	16	−204.1	(2, 4)
	$FeCl_2$	1.4331	16	2.56	(2, 4)
	$HgCl_2$	1.0381	16	13.7	(24)
	$Hg(CN)_2$	1.0638	16	7.1	(24)
	KCl	1.600		16.5	(2, 4)
	KBr	1.1424	20	16.3	(12)

TABLE 6.—(*Continued*)

Solvent	Solute	d	t	V_D	Lit.
H_2O.—(*Cont'd*)..	KI	1.6743	15	34.1	(2, 4)
	KNO_3	1.0634	20	13	(12)
	$KHCO_3$	1.1906	20	14.0	(12)
	$K_2Cr_2O_7$	1.0786	15	12.6	(33)
	$MgSO_4$	1.1147	16	3.6	(24)
	$MnSO_4$	1.1212	16	4.0	(24)
	NaCl	1.2051	16	18.2	(2, 4)
	Na_2SO_4	1.0661	20	13.5	(12)
	Na_2CO_3	1.1006	20	14.0	(12)
	$NiCl_2$	1.4685		27.3	(2, 4)
	$SbCl_3$			29.9	(2, 4)
	$SnCl_2$	1.3280	15	26.6	(33)
	$ZnCl_2$	1.2851	16	19.6	(33)
	KI + HgI_2	concentrated		128 *ca.*	(9)
HCl.....	$BiCl_3$	2.0822	16	39.6	(2)
	$SbCl_3$	2.4755	16	60.3	(2)
CH_3OH.....	Fe_2Cl_6	†	19	− 1.592	(20)
C_2H_5OH.....	$CaBr_2$	0.9966	20	15.4	(12)
	$CdCl_2$	0.8303	20	11.8	(12)
	$CdBr_2$	1.0446	20	15.9	(12)
	CdI_2	1.0988	20	19.9	(12)
	$HgCl_2$	0.9988	16	10.9	(24)
	$HgCl_2$	0.8857	16	12.1	(24)
	HgI_2	0.8072	16	24.4	(24)
	$Hg(CN)_2$	0.8527	16	6.4	(24)
	$Hg(CN)_2$	0.8348	16	5.3	(24)
	$SrCl_2$	0.8313	20	11.8	(12)
	$SrBr_2$	0.9636	20	14.0	(12)
C_3H_6O‡.....	$HgCl_2$	1.0388	21	10.8	(24)
$C_5H_{11}OH$§.....	$HgCl_2$	0.8955	16	12.6	(24)
C_5H_5N‖.....	$HgCl_2$	1.1523	16	12.6	(24)
	HgI_2	1.1054	16	23.1	(24)
	$Hg(CN)_2$	1.2816	16	6.1	(24)

* *See also* Table 11.
† $0.54Fe_2Cl_6 + 0.46CH_3OH$, by weight.
‡ Acetone.
§ Amyl alcohol.
‖ Pyridine.

TABLE 7.—VERDET CONSTANT FOR SOLUTIONS OF ORGANIC SUBSTANCES (25)

For specific magnetic rotatory power, *see* Table 10
Assumes for water at 4°C, $V_{Hg} = 0.01551'$ per cm-gauss; $\lambda_{Hg} = 5461$ Å
Temperature (t) in °C. Unit of $V = 0.001'$ per cm-gauss; $\lambda = 1$ Å

$100\tau_2$	t	V		
		λ5893	λ5461	λ4360
Water (H_2O)—Acetone (C_3H_6O)				
0.000	15.4	13.09	15.49	25.08
23.799	16	12.96	15.34	24.98
49.535	15.3	12.60	14.90	24.39
73.552	16	12.02	14.24	23.36
100.000	15.1	11.09	13.10	21.54
Water (H_2O)—*n*-Propyl alcohol (C_3H_8O)				
0.000	15.4	13.09	15.48	25.08
20.733	15.5	13.08	15.52	25.18
39.165	14.9	12.77	15.28	24.84
100.000	17.3	11.81	14.08	22.98

TABLE 7.—(*Continued*)

$100\tau_2$	t	V		
		λ5893	λ5461	λ4360
CCl_4—Acetic acid ($C_2H_4O_2$)				
0.000	15	16.03	18.94	31.23
35.564	15.1	13.22	15.53	25.41
58.272	14.9	12.00	13.93	23.01
78.681	15	11.11	13.06	21.34
100.000	15.2	10.35	12.16	19.91
CS_2—Acetic acid ($C_2H_4O_2$)				
0.000	15.6	42.35	50.70	90.63
12.076	15.2	33.12	42.80	75.38
50.354	15.5	22.38	26.55	45.45
61.284	16.8	19.39	22.99	39.01
77.605	16	15.34	18.14	30.47
100.000	15.2	10.35	12.16	19.91
CS_2—Isobutyric acid ($C_4H_8O_2$)				
0.000	15.6	42.35	50.70	90.63
20.336	14.5	32.60	38.93	67.83
45.276	14.6	24.15	28.35	48.99
49.112	14.9	23.12	27.29	46.70
100.000	15	11.35	13.23	21.90
CS_2—Isobutyl alcohol ($C_4H_{10}O$)				
0.000	15.6	42.35	50.70	90.63
15.803	16	33.99	40.50	70.78
50.080	15.7	22.73	26.88	45.95
75.360	16.5	16.94	19.96	33.56
100.000	16.1	12.66	14.86	24.35
CS_2—Isovaleric acid ($C_5H_{10}O_2$)				
0.000	15.6	42.35	50.70	90.63
32.725	15.8	28.30	33.66	58.36
46.203	16.4	24.14	28.68	49.49
50.099	15.4	23.19	27.46	47.15
63.543	17.1	19.69	23.36	39.68
100.000	15.0	12.08	14.20	23.16

TABLE 8.—VERDET CONSTANT IN INFRA-RED (13)

Temperature = 23°C; concentration expressed in % by weight; unit of $\lambda = 1\mu = 0.001$ mm $= 10^4$ Å; $d = 1$ g cm^{-3}; $V = 0.001'$ per cm-gauss

Pure Substances

Compound		λ=0.6	0.8	1.0	1.5	2.0
CCl_4	Carbon tetrachloride.	16.1	8.9	5.7	2.5	1.3
$SnCl_4$	Tin tetrachloride.....	40.8	21.7	13.5	6.0	3.1
$TiCl_4$	Titanium tetrachloride.....	−13.1	−5.0	−2.6	−1.0	−0.5
CS_2	Carbon disulfide.....	39.4	21.4	13.5	5.8	3.1
H_2O	Water.....	12.6	7.0	4.4	(2.9; λ = 1.25)	
$CHCl_3$	Chloroform.....	15.5	8.6	5.6	2.4	1.3
C_7H_{16}	*n*-Heptane.....	11.9	6.6	4.3	1.8	0.9
C_6H_6	Benzene.....	28.1	15.3	9.5	3.9	2.2
C_7H_8	Toluene.....	25.8	13.7	8.7	3.5	2.0
C_8H_{10}	Xylene.....	23.2	12.8	8.0	3.5	1.9
CH_3I	Methyl iodide.....	31.8	17.8	11.2	4.8	2.7
C_2H_5I	Ethyl iodide.....	27.9	15.1	9.7	4.1	2.4
CH_2I_2	Methylene iodide.....	47.6	26.8	16.9	7.3	4.0
$C_6H_5NO_2$	Nitrobenzene.....	20.9	11.4	7.3	3.1	1.8
$C_{10}H_7Br$	α-Bromonaphthalene.	46.0	24.5	15.2	6.3	3.5
CH_4O	Methyl alcohol.....	9.3	5.1	3.2	1.9	1.3
C_2H_6O	Ethyl alcohol.....	11.1	6.0	3.8	1.9	1.0
$C_4H_{10}O$	*n*-Butyl alcohol.....	12.0	6.7	4.3	1.8	1.4
C_3H_6O	Acetone.....	10.3	6.1	4.0	1.7	0.9
$C_4H_{10}O$	Ethyl ether.....	10.2	5.8	3.6	1.6	0.8

TABLE 8.—(*Continued*)

Aqueous Solutions

Solute	λ = 0.6	0.8	1.0	1.25	*d*	%
$Ce(NO_3)_3$	6.2	3.9	2.4	1.6	1.202	
$CoCl_2$		9.6	6.6		1.296	
$Co(NO_3)_2$	9.9	6.0	4.3	2.9	1.308	29.2
$CoSO_4$		6.5	4.6		1.322	
$Co(NH_4)_2(SO_4)_2$	12.6	7.1	4.9	3.5	1.106	
$Cr(NO_3)_3$		6.6	4.1	2.5	1.087	
$Cr_2(SO_4)_3$		6.7	4.5	2.8	1.140	
Fe_2Cl_6	10.7	6.1	4.0	2.6	1.049	6.3
Fe_2Cl_6		39.9	21.5	11.0	1.523	47.8
$Fe_2(SO_4)_3$		2.9	2.0	1.6	1.446	
$FeSO_4$	8.7	5.0				
$Fe_2(NH_4)_2(SO_4)_4$	7.8	4.4	2.1	2.6	1.250	24.5
$K_3Fe(CN)_6$	23.3	5.6	1.7	0.1	1.187	31.4
$K_4Fe(CN)_6$	14.7	7.8	5.1	3.2		
K_2CrO_4	9.2	6.0	4.1	2.6	1.372	38.2
$K_2Cr_2O_7$	10.8	6.4	4.2	2.5	1.085	12.1
$MnCl_2$	14.1	7.8	5.4	3.4	1.326	31.3
$MnSO_4$	17.8	10.1	6.6	4.3	1.369	31.0
$Ni(NH_4)_2(SO_4)_2$	13.9	7.5	4.8	3.0	1.054	
$KI + HgI_2$	84.1	42.2	24.9	15.2	2.445	

TABLE 9.—MOLECULAR MAGNETIC ROTATORY POWER RELATIVE TO WATER ([Ω]).—PURE SUBSTANCES

$[\Omega] = M[\omega]/M'[\omega]' = MVd'/M'V'd$, where M', $[\omega]'$, V', d' refer to water at the same temperature and for the same wave-length

Temperature (t) in °C; $\lambda_D = 5893$ Å; $\lambda_{Hg} = 5461$ Å; * denotes $[\Omega]_{Hg}$

Formula	Name	*t*	$[\Omega]_D$	Lit.
CS_2	Carbon disulfide	15	10.751	(18)
		20	10.86*	(15)
CCl_4	Carbon tetrachloride	23.5	6.613	(18)
		25	6.599	(31)
$CHBr_3$	Bromoform	20	11.614	(18)
$CHCl_3$	Chloroform	15	5.575	(18)
		25	5.568	(31)
CH_2Br_2	Methylene bromide	18	8.145	(18)
CH_2Cl_2	Methylene chloride	14	4.347	(18)
CH_2I_2	Methylene iodide	17	18.83	(18)
CH_2O_2	Formic acid	20	1.653	(18)
		20	1.67*	(15)
CH_3Br	Methyl bromide	1.5	4.644	(18)
CH_3I	Methyl iodide	19.6	9.005	(18)
CH_4O	Methyl alcohol	20	1.63	(18)
		20	1.60*	(15)
$C_2HCl_3O_2$	Trichloroacetic acid	15	6.473	(18)
$C_2H_2Cl_2O_2$	Dichloroacetic acid	15	5.300	(18)
C_2H_3Br	Bromoethylene	11	6.203	(18)
$C_2H_3BrCl_2$	1-Bromo-2, 2-dichloroethane	21.6	10.995	(18)
$C_2H_3Br_3$	1, 1, 2-Tribromoethane	12	12.891	(18)
C_2H_3ClO	Acetyl chloride		3.800	(18)
$C_2H_3ClO_2$	Chloroacetic acid	15	3.882	(18)
$C_2H_3Cl_3$	1, 1, 1-Trichloroethane	20.8	6.762	(18)
$C_2H_3Cl_3$	1, 1, 2-Trichloroethane	20	6.804	(18)
$C_2H_4Br_2$	1, 2-Dibromoethane	18	9.708	(18)
$C_2H_4Cl_2$	1, 1-Dichloroethane	15	5.34	(18)
		21	5.36	(27)
$C_2H_4Cl_2$	1, 2-Dichloroethane	15	5.485	(18)
		21	5.518	(27)
		25	5.537	(31)
C_2H_4O	Acetaldehyde	15	2.932	(18)
$C_2H_4O_2$	Acetic acid	20	2.531	(18)
		20	2.49*	(15)
$C_2H_4O_2$	Methyl formate	16.5	2.495	(18)
		20	2.49*	(15)
C_2H_5Br	Ethyl bromide	20	5.83	(18)
C_2H_5Cl	Ethyl chloride	5	4.039	(18)
C_2H_5I	Ethyl iodide	16	10.104	(18)
C_2H_6O	Ethyl alcohol	20	2.76	(18)
		25	2.768	(31)
		20	2.76*	(15)
$C_2H_6O_2$	Glycol	15	2.94	(18)
		20	2.88*	(15)

TABLE 9.—(*Continued*)

Formula	Name	*t*	$[\Omega]_D$	Lit.
$C_3H_4O_4$	Malonic acid	23.2	3.474	(18)
C_3H_5Br	1-Bromopropylene	22	7.289	(18)
C_3H_5Br	3-Bromopropylene	19	8.227	(18)
$C_3H_5Br_3$	1, 2, 3-Tribromopropane	22.8	14.050	(18)
C_3H_5Cl	3-Chloropropylene	18	6.04	(18)
$C_3H_5Cl_3$	1, 2, 3-Trichloropropane	16	7.904	(18)
C_3H_5I	3-Iodopropylene	20	12.785	(18)
$C_3H_6Br_2$	1, 2-Dibromopropane	15	10.827	(18)
$C_3H_6Br_2$	2, 2-Dibromopropane	20	10.145	(18)
$C_3H_6Br_2$	1, 3-Dibromopropane	20	10.337	(18)
$C_3H_6Cl_2$	1, 2-Dichloropropane	15	6.328	(18)
C_3H_6O	Acetone	15.2	3.514	(18)
		25	3.471	(31)
		20	3.48*	(15)
C_3H_6O	Allyl alcohol	20	4.692	(18)
C_3H_6O	Propionaldehyde	14.4	3.335	(18)
$C_3H_6O_2$	Propionic acid	20	3.46	(18)
		20	3.45*	(15)
$C_3H_6O_2$	Ethyl formate	20	3.56	(18)
		20	3.55*	(15)
$C_3H_6O_2$	Methyl acetate	22	3.36	(18)
		20	3.41*	(15)
C_3H_7Br	*n*-Propyl bromide	20	6.878	(18)
C_3H_7Br	Isopropyl bromide	18.6	6.995	(18)
C_3H_7Cl	Isopropyl chloride	19	5.160	(18)
C_3H_7I	*n*-Propyl iodide	20	11.056	(18)
C_3H_7I	Isopropyl iodide	23	11.162	(18)
C_3H_8O	Propyl alcohol	21	3.77	(18)
		20	3.74*	(15)
C_3H_8O	Isopropyl alcohol	18	4.013	(18)
		19.3	3.966	(27)
$C_3H_8O_3$	Glycerol	16.5	4.118	(18)
		20	4.07*	(15)
$C_4H_2Cl_2O_2$	Fumaryl chloride	15.6	8.747	(18)
$C_4H_2O_3$	Maleic anhydride	9.94	4.548	(18)
$C_4H_4Cl_2O_2$	Succinyl chloride	10.6	7.242	(18)
$C_4H_4O_4$	Maleic acid	24.8	5.633	(18)
C_4H_4S	Thiophene	15	9.578	(18)
$C_4H_6Br_2$	1, 2-Dibromoisobutylene	15	11.88	(18)
C_4H_8O	Isobutyric aldehyde	22	4.314	(18)
$C_4H_8O_2$	*n*-Butyric acid	20	4.47	(18)
		20	4.44*	(15)
$C_4H_8O_2$	Isobutyric acid	20	4.47	(18)
		20	4.44*	(15)
$C_4H_8O_2$	Propyl formate	21.5	4.50	(18)
$C_4H_8O_2$	Isopropyl formate	20	4.74*	(15)
$C_4H_8O_2$	Ethyl acetate	18	4.46	(18)
		20	4.48*	(15)
$C_4H_8O_2$	Methyl propionate	20	4.36*	(15)
C_4H_9Br	Isobutyl bromide	18.5	8.02	(18)
C_4H_9Br	*tert.*-Butyl bromide	20	8.248	(18)
C_4H_9Cl	Isobutyl chloride	20	6.144	(18)
C_4H_9Cl	*tert.*-Butyl chloride	17.6	6.248	(18)
C_4H_9I	Isobutyl iodide	21	12.183	(18)
$C_4H_{10}O$	Ethyl ether	20	4.77	(18)
		20	4.80*	(15)
$C_4H_{10}O$	*n*-Butyl alcohol	20	4.72*	(15)
$C_4H_{10}O$	Isobutyl alcohol	20	4.95	(18)
$C_4H_{10}O$	Trimethyl carbinol	22	5.107	(18)
$C_4H_{10}O_2$	Dimethyl acetal	15.5	4.64	(18)
$C_4H_{10}O_4$	Erythritol	15	5.23	(19)
$C_5H_4O_3$	Citraconic anhydride	15.6	5.540	(18)
C_5H_5N	Pyridine	15	8.748	(18)
$C_5H_6O_3$	Pyrotartaric anhydride	11.6	4.764	(18)
$C_5H_6O_4$	Citraconic acid	15.6	6.567	(18)
$C_5H_8O_4$	Dimethyl malonate	18	5.273	(18)
$C_5H_8O_4$	Glutaric acid	13.3	5.482	(18)
C_5H_{10}	*n*-Propylethylene	18	6.113	(18)
		23.6	6.180	(27)
$C_5H_{10}Br_2$	2, 3-Dibromoisopentane	14.4	12.933	(18)
$C_5H_{10}O$	Isovaleraldehyde	14.5	5.478	(18)
$C_5H_{10}O$	Diethyl ketone	21	5.434	(27)
$C_5H_{10}O_2$	Valeric acid	14	5.50	(18)
$C_5H_{10}O_2$	Isovaleric acid	16	5.65	(18)
		20	5.57*	(15)
$C_5H_{10}O_2$	Propyl acetate	15	5.49	(18)
		20	5.45*	(15)
$C_5H_{10}O_2$	Ethyl propionate	15	5.456	(18)

TABLE 9.—(*Continued*)

Formula	Name	t	$[\Omega]_D$	Lit.
$C_5H_{10}O_2$	Methyl butyrate	16.4	5.38	(18)
		20	5.37*	(15)
$C_5H_{11}Br$	Isoamyl bromide	18	9.073	(18)
$C_5H_{11}Cl$	Isoamyl chloride	20	7.169	(18)
$C_5H_{11}Cl$	*tert.*-Amyl chloride	22	7.206	(18)
$C_5H_{11}I$	Isoamyl iodide	18	13.246	(18)
C_5H_{12}	Pentane	20	5.647	(18)
		21.1	5.811	(27)
C_5H_{12}	Isopentane	21.5	5.76	(18)
$C_5H_{12}O$	Ethyldimethyl carbinol	20	5.99	(18)
$C_5H_{12}O$	*act.*-Amyl alcohol	20	5.95	(18)
$C_5H_{12}O$	Isobutyl carbinol	20	5.96	(18)
$C_6H_4N_2O_4$	*m*-Dinitrobenzene	15	9.647	(18)
C_6H_5Br	Bromobenzene	15	14.506	(18)
C_6H_5Cl	Chlorobenzene	15	12.510	(18)
C_6H_5F	Fluorobenzene	15	9.970	(18)
C_6H_5I	Iodobenzene	15	19.108	(18)
$C_6H_5NO_2$	Nitrobenzene	15	9.361	(18)
$C_6H_5N_3$	Triazobenzene	15	14.769	(18)
C_6H_6	Benzene	15	11.284	(18)
		25	11.23	(31)
		27	11.23	(27)
C_6H_6ClN	*m*-Chloroaniline	15	16.969	(18)
C_6H_6ClN	*p*-Chloroaniline	15	17.066	(18)
C_6H_6O	Phenol	15	12.14	(18)
$C_6H_6O_2$	Resorcinol	15	12.285	(18)
$C_6H_6O_2$	Pyrocatechol	15	13.022	(18)
$C_6H_6O_3$	Pyrogallol	15	13.029	(18)
C_6H_7N	Aniline	15	16.076	(18)
C_6H_8ClN	Aniline hydrochloride (anhydrous)	15	16.394	(18)
C_6H_8ClN	Aniline hydrochloride (in solution)	15	15.547	(18)
$C_6H_8N_2$	*o*-Phenylenediamine	15	19.391	(18)
$C_6H_8N_2$	*m*-Phenylenediamine	15	18.843	(18)
$C_6H_8N_2$	Phenylhydrazine	15	18.061	(18)
$C_6H_{10}Cl_2N_2$	*o*-Phenylenediamine hydrochloride (in solution)	15	21.329	(18)
$C_6H_{10}Cl_2N_2$	*m*-Phenylenediamine hydrochloride (in solution)	15	20.345	(18)
$C_6H_{10}Cl_2N_2$	*p*-Phenylenediamine hydrochloride (in solution)	15	20.213	(18)
$C_6H_{10}O_2$	Ethyl α-crotonate	22.5	7.567	(18)
$C_6H_{10}O_3$	Ethyl acetoacetate	19	6.48	(18)
$C_6H_{10}O_4$	Glycol diacetate	15	6.43	(18)
$C_6H_{10}O_4$	Diethyl oxalate	15	6.636	(18)
$C_6H_{10}O_4$	Dimethyl succinate	18.5	6.242	(18)
C_6H_{12}	Hexylene	24	7.453	(27)
$C_6H_{12}O$	Pinacolin	20	6.32*	(15)
$C_6H_{12}O_2$	Isobutyl acetate	10	6.63	(18)
$C_6H_{12}O_2$	Propyl propionate	20	6.42	(18)
$C_6H_{12}O_2$	Isopropyl propionate	18	6.60	(18)
$C_6H_{12}O_2$	Ethyl butyrate	19	6.50	(18)
$C_6H_{12}O_2$	Ethyl isobutyrate	18.8	6.48	(18)
$C_6H_{12}O_3$	Paraldehyde	18	6.653	(18)
$C_6H_{12}O_6$	Fructose	15	6.789	(19)
$C_6H_{12}O_6$	Galactose	15	6.887	(19)
$C_6H_{12}O_6$	Glucose	15	6.723	(19)
$C_6H_{13}I$	*sec.*-Hexyl iodide	22	14.243	(18)
C_6H_{14}	Diisopropyl	15	6.784	(18)
C_6H_{14}	Hexane	11	6.67	(18)
		22.5	6.66	(27)
		20	6.62*	(15)
C_6H_{14}	Isohexane	20	6.785	(18)
$C_6H_{14}O$	2, 2-Dimethyl-3-butanol	20	7.06*	(15)
$C_6H_{14}O_2$	Diethyl acetal	15	6.96	(18)
$C_6H_{14}O_2$	Pinacol	21	7.23	(18)
$C_6H_{14}O_6$	Mannitol	15	7.351	(19)
C_7H_5ClO	Benzoyl chloride	15	12.385	(18)
C_7H_5N	Benzonitrile	15	11.857	(18)
C_7H_5NS	Phenyl isothiocyanate	15	21.526	(18)
C_7H_6O	Benzaldehyde	15	11.864	(18)
$C_7H_6O_2$	Salicyl aldehyde	15	13.286	(18)
C_7H_7Br	*o*-Bromotoluene	15	15.674	(18)
C_7H_7Br	*p*-Bromotoluene	15	15.167	(18)
C_7H_7Cl	*o*-Chlorotoluene	15	13.719	(18)
C_7H_7Cl	*p*-Chlorotoluene	15	13.246	(18)
C_7H_7NO	Benzamide	15	13.520	(18)
C_7H_7NO	Formanilide	15	15.211	(18)
$C_7H_7NO_2$	*o*-Nitrotoluene	15	10.806	(18)
$C_7H_7NO_2$	*p*-Nitrotoluene	15	10.214	(18)

TABLE 9.—(*Continued*)

Formula	Name	t	$[\Omega]_D$	Lit.
C_7H_8	Toluene	15	12.157	(18)
		28.4	12.031	(27)
C_7H_8O	Benzyl alcohol	15	12.400	(18)
C_7H_8O	*o*-Cresol	15	13.382	(18)
C_7H_8O	*m*-Cresol	15	12.776	(18)
C_7H_8O	*p*-Cresol	15	12.869	(18)
C_7H_8O	Phenyl methyl ether	15	13.958	(18)
$C_7H_8O_2$	Homopyrocatechol	15	13.306	(18)
$C_7H_8O_2$	Guaiacol	15	14.689	(18)
C_7H_9N	*o*-Toluidine	15	17.200	(18)
C_7H_9N	*m*-Toluidine	15	16.210	(18)
C_7H_9N	*p*-Toluidine	15	16.188	(18)
C_7H_9N	Methylaniline	15	19.624	(18)
C_7H_9N	Benzylamine	15	13.646	(18)
C_7H_9NO	*o*-Anisidine	15	18.722	(18)
C_7H_9NO	*p*-Anisidine	15	18.306	(18)
$C_7H_{10}O_4$	Dimethyl mesaconate	14.4	9.061	(18)
$C_7H_{10}O_4$	Dimethyl citraconate	13	8.364	(18)
$C_7H_{12}O_2$	Dimethylacetylacetone	15	7.045	(18)
$C_7H_{12}O_4$	Diethyl malonate	15	7.41	(18)
$C_7H_{14}O$	Dipropyl ketone	15	7.47	(18)
		20	7.32*	(15)
$C_7H_{14}O$	Diisopropyl ketone	20	7.36*	(15)
$C_7H_{14}O$	Heptaldehyde	19	7.405	(18)
$C_7H_{14}O_2$	*n*-Heptylic acid	20	7.55	(18)
$C_7H_{14}O_2$	Ethyl isovalerate	19.5	7.60	(18)
C_7H_{16}	*n*-Heptane	15	6.666	(18)
$C_7H_{16}O$	*n*-Heptyl alcohol	15	7.84	(18)
		20	7.78*	(15)
$C_8H_4Cl_2O_2$	Phthalyl chloride	15	14.183	(18)
C_8H_6O	Coumarone	15	14.807	(18)
C_8H_7ClO	ω-Chloroacetophenone	15	14.091	(18)
C_8H_7N	*o*-Tolunitrile	15	12.980	(18)
C_8H_7N	*p*-Tolunitrile	15	12.999	(18)
C_8H_7N	Benzyl cyanide	15	12.472	(18)
C_8H_8	Phenylethylene	15	16.041	(18)
C_8H_8O	Acetophenone	15	12.597	(18)
$C_8H_8O_2$	Phenyl acetate	15	12.953	(18)
$C_8H_8O_2$	Phenylacetic acid	15	12.743	(18)
$C_8H_8O_2$	Methyl benzoate	15	12.743	(18)
$C_8H_8O_2$	*o*-Methoxybenzaldehyde	15	14.187	(18)
$C_8H_8O_2$	Anisaldehyde	15	15.872	(18)
$C_8H_8O_3$	Methyl salicylate	15	14.266	(18)
C_8H_9NO	Acetaanilide	15	16.003	(18)
C_8H_9NO	Phenylacetamide	15	15.208	(18)
C_8H_{10}	*o*-Xylene	15	13.345	(18)
		27	13.306	(27)
C_8H_{10}	*m*-Xylene	15	12.859	(18)
		28.4	12.731	(27)
C_8H_{10}	*p*-Xylene	15	12.810	(18)
		27	12.789	(27)
C_8H_{10}	Ethylbenzene	15	13.414	(18)
		28.2	13.327	(27)
$C_8H_{10}O$	*o*-Tolyl methyl ether	15	15.190	(18)
$C_8H_{10}O$	*m*-Tolyl methyl ether	15	14.646	(18)
$C_8H_{10}O$	*p*-Tolyl methyl ether	15	14.712	(18)
$C_8H_{10}O$	Benzyl methyl ether	15	13.417	(18)
$C_8H_{10}O$	Phenyl ethyl ether	15	15.129	(18)
$C_8H_{10}O$	Phenylmethyl carbinol	20	16.01*	(15)
$C_8H_{10}O_2$	Anisyl alcohol	15	15.407	(18)
$C_8H_{10}O_2$	Creosol	15	15.405	(18)
$C_8H_{10}O_2$	Dimethylresorcinol	15	15.108	(18)
$C_8H_{10}O_2$	Dimethylquinol	15	16.717	(18)
$C_8H_{10}O_2$	Methylsaligenin	15	14.828	(18)
$C_8H_{10}O_2$	3-Hydroxy-4-methoxytoluene	15	15.021	(18)
$C_8H_{10}O_2$	Veratrol	15	16.837	(18)
$C_8H_{10}O_4$	Diethyl acetylenedicarboxylate	25	9.617	(16)
$C_8H_{11}N$	Ethylaniline	15	20.567	(18)
$C_8H_{11}N$	Dimethylaniline	15	22.888	(18)
$C_8H_{12}ClN$	Dimethylaniline hydrochloride (anhydrous)	15	18.326	(18)
$C_8H_{12}ClN$	Dimethylaniline hydrochloride (in solution)	15	17.604	(18)
$C_8H_{12}N_2$	*p*-Aminodimethylaniline	15	26.239	(18)
$C_8H_{12}O_4$	Diethyl fumarate	11.1	10.112	(18)
$C_8H_{12}O_4$	Diethyl maleate	15	9.625	(18)
$C_8H_{13}NO$	Amylpropiolamide	25	10.653	(17)
C_8H_{14}	*n*-Hexylacetylene	25	9.310	(17)
$C_8H_{14}O_4$	Glycol dipropionate	15	8.349	(18)

TABLE 9.—(*Continued*)

Formula	Name	t	$[\Omega]_D$	Lit.
$C_8H_{14}O_4$	Diethyl succinate	20	8.379	(18)
$C_8H_{14}O_4$	Diethyl isosuccinate	19.2	8.324	(18)
C_8H_{16}	Octylene	24	9.406	(27)
$C_8H_{16}O$	Isopropyl *n*-butyl ketone	20	8.43*	(15)
$C_8H_{16}O_2$	Caprylic acid	20	8.56	(18)
$C_8H_{16}O_2$	Ethyl caproate	18.8	8.502	(18)
$C_8H_{17}Cl$	Octyl chloride	20	10.138	(18)
$C_8H_{17}Cl$	*sec.*-Octyl chloride	20	10.25	(18)
$C_8H_{17}I$	Octyl iodide	19.3	16.213	(18)
C_8H_{18}	Octane	23.1	8.722	(27)
$C_8H_{18}O$	Octyl alcohol	20	8.89	(18)
		20	8.87*	(15)
$C_8H_{18}O$	*sec.*-Octyl alcohol	13.5	8.99	(18)
$C_9H_6O_2$	Phenylpropiolic acid	25	16.659†	(17)
C_9H_7N	Quinoline	15	20.875	(18)
C_9H_7NO	Phenylpropiolamide	25	18.43‡	(17)
C_9H_8	Indene (synthetic)	15	16.202	(18)
C_9H_8O	Hydrindone	15	13.768	(18)
C_9H_8O	Cinnamaldehyde	15	17.885	(18)
C_9H_{10}	Allylbenzene	15	17.599	(18)
C_9H_{10}	Hydrindene (synthetic)	15	13.928	(18)
$C_9H_{10}O$	Cinnamic alcohol	15	17.940	(18)
$C_9H_{10}O$	Phenyl allyl ether	15	17.134	(18)
$C_9H_{10}O$	Phenyl ethyl ketone	15	13.635	(18)
$C_9H_{10}O_2$	Phenyl propionate	15	13.673	(18)
$C_9H_{10}O_3$	Ethyl salicylate	15	15.366	(18)
$C_9H_{11}N$	Tetrahydroquinoline	15	19.619	(18)
C_9H_{12}	Propylbenzene	15	14.553	(18)
		25.6	14.394	(27)
C_9H_{12}	Isopropylbenzene	15	14.633	(18)
		27	14.440	(27)
C_9H_{12}	Mesitylene	15	13.366	(18)
		28.6	12.920	(27)
C_9H_{12}	Pseudocumene	15	13.998	(18)
		24.6	13.767	(27)
$C_9H_{12}O$	Phenyl propyl ether	15	16.187	(18)
$C_9H_{12}O$	Phenyl isopropyl ether	15	16.210	(18)
$C_9H_{12}O$	Benzylmethyl carbinol	20	13.87*	(15)
$C_9H_{12}O$	Phenylethyl carbinol	20	14.92*	(15)
$C_9H_{12}O_2$	Dimethylhomopyrocatechol	15	17.484	(18)
$C_9H_{12}O_3$	Trimethylpyrogallol	15	17.201	(18)
$C_9H_{13}N$	Dimethyl-*o*-toluidine	15	18.617	(18)
$C_9H_{13}N$	Dimethyl-*p*-toluidine	15	22.842	(18)
$C_9H_{14}ClN$	Dimethyl-*o*-toluidine hydrochloride (in solution)	15	18.705	(18)
$C_9H_{14}ClN$	Dimethyl-*p*-toluidine hydrochloride (in solution)	15	18.465	(18)
$C_9H_{14}O_2$	Hexylpropiolic acid	25	10.598	(17)
$C_9H_{14}O_3$	Ethyl allylacetoacetate	15	10.39	(18)
$C_9H_{14}O_4$	Diethyl citraconate	15	10.497	(18)
$C_9H_{14}O_4$	Diethyl mesaconate	16.3	11.233	(18)
$C_9H_{14}O_4$	Diethyl itaconate	17.6	10.467	(18)
$C_9H_{16}O_4$	Diethyl dimethylmalonate	18.5	9.24	(18)
$C_9H_{16}O_4$	Diethyl ethylmalonate	15	9.27	(18)
$C_9H_{16}O_4$	Diethyl methylsuccinate	18.5	9.332	(18)
$C_9H_{16}O_4$	Diethyl glutarate	12.5	9.356	(18)
$C_9H_{18}O$	Isopropyl *n*-amyl ketone	20	9.40*	(15)
$C_9H_{18}O_2$	Nonylic acid	20	9.60	(18)
$C_9H_{18}O_2$	Ethyl oenanthate	15	9.54	(18)
$C_{10}H_7NO_2$	α-Nitronaphthalene	15	20.840	(18)
$C_{10}H_8$	Naphthalene	15	25.125	(18)
$C_{10}H_8O$	Acetylphenylacetylene	25	17.146	(17)
$C_{10}H_8O_2$	Methyl phenylpropiolate	25	17.752	(17)
$C_{10}H_9N$	α-Naphthylamine	15	37.478	(18)
$C_{10}H_9N$	β-Naphthylamine	15	35.700	(18)
$C_{10}H_{10}O$	Benzalacetone	15	19.235	(18)
$C_{10}H_{10}O_2$	Allyl benzoate	15	15.722	(18)
$C_{10}H_{12}$	Isobutenylbenzene	15	18.362	(18)
$C_{10}H_{12}O$	Cuminaldehyde	15	15.245	(18)
$C_{10}H_{12}O$	*p*-Tolyl allyl ether	15	17.571	(18)
$C_{10}H_{12}O$	Anethol	15	21.089	(18)
$C_{10}H_{12}O_2$	Ethyl *o*-toluate	15	15.065	(18)
$C_{10}H_{12}O_2$	Ethyl *p*-toluate	15	14.744	(18)
$C_{10}H_{12}O_2$	Phenyl butyrate	15	14.761	(18)
$C_{10}H_{12}O_2$	Ethyl phenylacetate	15	14.982	(18)
$C_{10}H_{12}O_2$	Propyl benzoate	15	14.873	(18)
$C_{10}H_{12}O_2$	Isopropyl benzoate	15	14.950	(18)
$C_{10}H_{12}O_2$	Eugenol	15	18.727	(18)
$C_{10}H_{12}O_3$	Ethyl anisate	15	17.285	(18)

TABLE 9.—(*Continued*)

Formula	Name	t	$[\Omega]_D$	Lit.
$C_{10}H_{12}O_3$	Ethyl *o*-methoxybenzoate	15	17.156	(18)
$C_{10}H_{12}O_3$	Ethyl *m*-methoxybenzoate	15	16.679	(18)
$C_{10}H_{13}Br_2ClO$	α, β-Dibromochlorocamphor§	13.1	17.303	(19)
$C_{10}H_{13}N$	*ar*-Tetrahydro-β-naphthylamine	15	20.058	(18)
$C_{10}H_{13}N$	*ac*-Tetrahydro-β-naphthylamine	15	16.147	(18)
$C_{10}H_{14}$	Isobutylbenzene	15	15.615	(18)
		23.6	15.531	(27)
$C_{10}H_{14}$	Cymene	15	15.255	(18)
		25.7	14.892	(27)
$C_{10}H_{14}BrNO_3$	α, α′-Bromonitrocamphor§‖	12.7	12.720	(19)
$C_{10}H_{14}Br_2O$	α, α-Dibromocamphor§‖	15.52	15.994	(19)
$C_{10}H_{14}Br_2O$	α, β-Dibromocamphor§¶	14.9	15.902	(19)
$C_{10}H_{14}ClNO_3$	α, α′-Chloronitrocamphor§**	12.85	10.822	(19)
$C_{10}H_{14}O$	Cuminyl alcohol	15	15.879	(18)
$C_{10}H_{14}O$	Phenyl isobutyl ether	15	17.332	(18)
$C_{10}H_{14}O$	*l*-Phenylethylmethyl carbinol	20	14.93*	(15)
$C_{10}H_{14}O$	Carvacrol	15	16.313	(18)
$C_{10}H_{14}O$	Thymol	15	16.120	(18)
$C_{10}H_{15}BrO$	α-Bromocamphor§**	12.2	12.761	(19)
$C_{10}H_{15}ClO$	α-Chlorocamphor§††	12.4	10.846	(19)
$C_{10}H_{15}N$	Diethylaniline	15	25.163	(18)
$C_{10}H_{15}NO_3$	Camphoryloxime§‡‡	17.4	10.375	(19)
$C_{10}H_{15}NO_3$	α-Nitrocamphor§ §§	12.14	9.468	(19)
$C_{10}H_{16}$	Camphene	45.8	10.136	(19)
$C_{10}H_{16}$	*d*-Limonene	16.32	11.246	(19)
$C_{10}H_{16}$	*l*-Limonene	15	11.162	(19)
$C_{10}H_{16}$	Pinene	20	10.294	(19)
$C_{10}H_{16}O$	Camphor§‖‖	15.74	9.280	(19)
$C_{10}H_{16}O_2$	Ethyl amylpropiolate	25	11.556	(17)
$C_{10}H_{16}O_2$	Methyl hexylpropiolate	25	13.730	(17)
$C_{10}H_{16}O_4$	Diethyl allylmalonate	14	11.265	(18)
$C_{10}H_{16}O_5$	Diethyl acetosuccinate	22.5	10.33	(18)
$C_{10}H_{17}Cl$	Pinene hydrochloride¶¶	14.8	11.058	(19)
$C_{10}H_{18}Cl_2$	Dipentene dihydrochloride	54.8	13.111	(19)
$C_{10}H_{18}O$	Borneol§***	15.8	9.807	(19)
$C_{10}H_{18}O_4$	Diethyl propylmalonate	20	10.36	(18)
$C_{10}H_{18}O_4$	Diethyl isopropylmalonate	20	10.47	(18)
$C_{10}H_{19}N$	Camphylamine	16	11.770	(19)
$C_{10}H_{20}$	Decylene	23.7	11.247	(27)
$C_{10}H_{20}O$	Isobutyl amyl ketone	20	10.65*	(15)
$C_{10}H_{20}O_2$	Octyl acetate	15	10.63	(18)
$C_{10}H_{22}$	Decane	23	8.722	(27)
		20	8.70*	(15)
$C_{10}H_{22}O$	Isoamyl ether	15.6	11.168	(18)
$C_{10}H_{22}O$	Isopropyl *n*-hexyl ketone	20	10.44*	(15)
$C_{11}H_7N$	α-Naphthonitrile	15	24.788	(18)
$C_{11}H_7N$	β-Naphthonitrile	15	26.264	(18)
$C_{11}H_{10}O$	Propionylphenylacetylene	25	18.595	(17)
$C_{11}H_{10}O_2$	Ethyl phenylpropiolate	25	18.965	(17)
$C_{11}H_{12}O_2$	Ethyl cinnamate	15	20.006	(18)
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	15	16.411	(18)
$C_{11}H_{12}O_3$	α-Methyl *o*-methoxyphenylacrylate	15	21.891	(18)
$C_{11}H_{12}O_3$	β-Methyl *o*-methoxyphenylacrylate	15	22.359	(18)
$C_{11}H_{14}O_2$	Butyl benzoate	15	15.952	(18)
$C_{11}H_{14}O_2$	Isobutyl benzoate	15	16.048	(18)
$C_{11}H_{14}O_2$	Ethyl hydrocinnamate	15	16.169	(18)
$C_{11}H_{18}O_2$	Ethyl hexylpropiolate	25	12.576	(17)
$C_{11}H_{20}O_4$	Diethyl diethylmalonate	20.5	11.20	(18)
$C_{11}H_{22}O_2$	Ethyl pelargonate	18	11.56	(18)
$C_{12}H_{10}$	Diphenyl	15	25.304	(18)
$C_{12}H_{10}S$	Diphenyl sulfide	15	29.668	(18)
$C_{12}H_{12}O$	α-Naphthyl ethyl ether	15	32.237	(18)
$C_{12}H_{12}O$	β-Naphthyl ethyl ether	15	30.698	(18)
$C_{12}H_{12}O$	Butyrylphenylacetylene	25	19.911	(17)
$C_{12}H_{13}N$	Dimethyl-α-naphthylamine	15	35.994	(18)
$C_{12}H_{13}N$	Dimethyl-β-naphthylamine	15	47.377	(18)
$C_{12}H_{14}O_4$	Diethyl phthalate	15	16.909	(18)
$C_{12}H_{14}O_4$	Diethyl isophthalate	15	16.942	(18)
$C_{12}H_{14}O_4$	Diethyl terephthalate	15	16.117	(18)
$C_{12}H_{16}O_2$	Ethyl cumate	15	17.093	(18)
$C_{12}H_{22}O_4$	Diisobutyl succinate	15	12.71	(18)
$C_{12}H_{22}O_4$	Diethyl suberate	17.5	12.45	(18)
$C_{12}H_{22}O_{11}$	Maltose	15	12.690	(19)
$C_{12}H_{22}O_{11}$	Lactose	15	12.714	(19)
$C_{12}H_{22}O_{11}$	Saccharose	15	12.586	(19)
$C_{12}H_{24}O$	Isopropyl *n*-octyl ketone	20	12.48*	(15)
$C_{12}H_{26}O_4$	Diacetal	25	13.61	(17)
$C_{13}H_{10}O$	Benzophenone	15	23.371	(18)
$C_{13}H_{12}$	Diphenylmethane	15	23.845	(18)

TABLE 9.—(*Continued*)

Formula	Name	t	$[\Omega]_D$	Lit.
$C_{13}H_{12}O_2$	Ethyl α-naphthoate	15	27.161	(18)
$C_{13}H_{12}O_2$	Ethyl β-naphthoate	15	27.360	(18)
$C_{13}H_{13}N$	Methyldiphenylamine	15	34.878	(18)
$C_{13}H_{13}N$	Benzylaniline	15	31.295	(18)
$C_{13}H_{14}O$	Isovalerylphenylacetylene	25	21.168	(17)
$C_{13}H_{18}O_2$	Phenyl oenanthate	15	17.923	(18)
$C_{13}H_{20}O_4$	Diethyl diallylmalonate	22	14.99	(18)
$C_{14}H_{10}$	Phenanthrene	15	36.959	(18)
$C_{14}H_{12}$	Stilbene	15	33.143	(18)
$C_{14}H_{14}$	Dibenzyl	15	24.977	(18)
$C_{14}H_{14}S$	Dibenzyl sulfide	15	29.216	(18)
$C_{14}H_{15}N$	Dibenzylamine	15	25.879	(18)
$C_{14}H_{16}O$	Caproylphenylacetylene	25	21.435	(17)
$C_{14}H_{22}O$	Phenyl octyl ether	15	21.446	(18)
$C_{14}H_{26}O_4$	Diethyl sebacate	15	14.51	(18)
$C_{14}H_{28}O_2$	Heptyl oenanthate	15	14.64	(18)
$C_{15}H_{10}O$	Benzoylphenylacetylene	25	28.403	(17)
$C_{15}H_{22}O_2$	Octyl benzoate	15	19.992	(18)
$C_{18}H_{36}O_2$	Cetyl acetate	20	18.76	(18)
$C_{19}H_{16}$	Triphenylmethane	15	36.011	(18)
$C_{20}H_{28}N_2O_5$	Nitrocamphor anhydride§ †††	14.9	19.712	(19)

* Value for $\lambda_{Hg} = 5461$ Å.
† Dissolved in ethyl alcohol, $C = 10.215\%$ by weight.
‡ Dissolved in ethyl alcohol, $C = 11.57\%$ by weight.
§ Dissolved in ethylene chloride.
‖ $C = 100/7 = 14.3M\%$.
¶ $C = 10M\%$.
** $C = 25M\%$.
†† $C = 20M\%$.
‡‡ $C = 200/7 = 28.6M\%$.
§§ $C = 100/3 = 33.3M\%$.
‖‖ $C = 400/7 = 57.1M\%$.
¶¶ Dissolved in CCl_4; $C = 100/1.517 = 65.9M\%$
*** $C = 100/6 = 16.7M\%$.
††† $C = 100/21 = 4.76M\%$.

TABLE 10.—SPECIFIC MAGNETIC ROTATORY POWER OF SOLUTIONS

For Verdet constant for solutions, *see* Tables 6 and 7. $[\omega]_S = (1 + 1000\Delta)\{\tau_1[\omega]_1 + \tau_2[\omega]_2\}$; $\tau_2[\omega]'_2 = \{[\omega]_S - \tau_1[\omega]_1\}$. If $V_c \equiv V_1[1 + a\tau_2 + b\tau_2^2]$, $0 < \tau_2 < 1$, δ = max. deviation of V_c from observed V for the solution; V_1 = Verdet's constant for constituent No. 1. $R \equiv [\omega]'_2/[\omega]''$, where $[\omega]''$ = value for water at same temperature. Temperature 25°C, $\lambda = 5893$ Å = D-line; unit of $d = 1$ g per ml.

Water—Acetic acid ($C_2H_4O_2$) (32)

$100\tau_2$	d	R
12.868	1.0111	0.763
30.444	1.0364	0.798
48.577	1.0534	0.743
66.640	1.0637	0.750
97.120	1.0437	0.744

Water—Ethyl alcohol (C_2H_6O) (31)

$100\tau_2$	d	Δ
0	0.9971	0
7.542	0.9840	3.3
14.94	0.9735	1.0
20.43	0.9659	0
30.04	0.9507	0.6
41.59	0.9273	7.0
50.33	0.9092	6.6
62.76	0.8807	2.8
69.54	0.8648	5.5
79.40	0.8390	6.4
88.90	0.8167	7.7
100.00	0.7835	0

H_2O—HCl (32)

$100\tau_2$	d	R
$a = 1.880$; $b = 0$; $\delta = 0.2\%$		
14.319	1.0661	2.209
20.697	1.0977	2.178
25.568	1.1243	2.164
$t = 20°C$ (25)		
15.63	1.0758	2.196
25.60	1.1274	2.172
30.86	1.1564	2.120
36.50	1.1846	2.096
41.70	1.2051	2.008
100.00	0.8240	1.076

H_2O—H_2SO_4 (32)

18.972	1.1308	0.337
36.327	1.2693	0.347
62.553	1.5205	0.366
80.130	1.7304	0.392
97.717	1.8310	0.407

$100\tau_2$	d_{15}^{15}	Δ
$t = 15°$ (25)		
0	1.00000	0
9.179	1.06305	− 6.8
11.154	1.07706	− 8.3
14.019	1.09785	−11.2
18.921	1.13464	−14.9
28.005	1.20620	−22.0
35.165	1.26529	−28.2
47.407	1.37413	−41.9
57.938	1.47966	−41.8
64.413	1.55074	−44.1
72.998	1.65021	−42.7
84.349	1.77753	−31.6
93.663	1.83617	−15.2
96.598	1.84264	− 3.7
100.000	1.83840	0

H_2O—KCl (32)

$100\tau_2$	d	R
$a = 1.08$; $b = 0$; $\delta = 0.7\%$		
10.345	1.0724	1.282
19.143	1.1240	1.333
25.830	1.1833	1.270

H_2O—LiCl (32)

$a = 1.807$; $b = 0$; $\delta = 1.9\%$		
10.677	1.0623	2.076
21.102	1.1373	2.109
29.443	1.1818	1.991
31.504	1.2044	1.982
36.356	1.2285	1.928
40.755	1.2729	1.888
43.328	1.2894	1.860

H_2O—NH_4NO_3 (32)

$a = 0.148$; $b = 0$; $\delta = 0.36\%$		
10.485	1.0398	0.489
12.096	1.0412	0.507
20.589	1.0831	0.487
27.553	1.1142	0.504
49.378	1.2237	0.503
62.030	1.2869	0.526

H_2O—NaCl (32)

$a = 1.473$; $b = 0$; $\delta = 0.5\%$		
11.410	1.0882	.558
18.300	1.1318	1.604
24.292	1.1794	1.606

Chloroform ($CHCl_3$)—Acetone (C_3H_6O) (31)

$100\tau_2$	d	Δ
0	1.4783	0
10.95	1.3498	+ 1.2
22.53	1.2349	+ 6.1
29.04	1.1783	− 1.1
40.77	1.0878	+ 2.9
52.43	1.0113	0.0
58.82	0.9729	− 7.0
71.03	0.9086	−16.2
78.56	0.8727	− 1.6
85.25	0.8436	− 8.7
100.00	0.7856	0

Carbon tetrachloride (CCl_4)—Benzene (C_6H_6) (31)

0.00	1.5839	0
9.96	1.4651	10.5
18.03	1.3809	7.4
29.33	1.2785	11.0
42.73	1.1750	13.9
51.06	1.1188	16.9
59.32	1.0642	14.6
68.19	1.0186	+ 9.5
79.67	0.9960	−24.2
89.35	0.9172	+ 9.2
100.00	0.8736	0

Ethylene chloride ($C_2H_4Cl_2$)—Benzene (C_6H_6) (31)

0.00	1.2492	0
11.90	1.1860	− 4.7
20.79	1.1441	+ 3.3
26.31	1.1193	+ 8.2
34.25	1.0858	+ 1.7
49.23	1.0280	+ 6.0
58.01	0.9971	+ 2.0
67.87	0.9647	+ 3.7
77.21	0.9361	+ 6.3
86.37	0.9097	+ 4.4
100.00	0.8736	0

Ethyl alcohol (C_2H_6O)—Aniline (C_6H_7N) (32)

$a = 1.25$; $b = 1.06$; $\delta = 2.5\%$ if $\tau_2 > 0.29$

0.000	0.7865	0
9.805	0.8083	−13.5
20.485	0.8317	−33.4
29.707	0.8524	−26.8
36.370	0.8673	−31.6
50.878	0.9003	−30.0
59.609	0.9206	−38.8
71.458	0.9483	−26.3
80.992	0.9713	−21.9
88.728	0.9893	−16.3
100.00	1.0174	0

Benzene (C_6H_6)—Aniline (C_6H_7N) (32)

0.000	0.8725	0
11.893	0.8886	7.3
22.102	0.9026	4.6
34.378	0.9202	2.8
40.177	0.9284	4.2
52.061	0.9459	+ 0.4
61.486	0.9598	− 3.1
71.607	0.9747	+ 1.6
80.972	0.9889	3.6
88.176	0.9997	4.2
100.000	1.0174	0

Table 11.—Dispersion of Verdet Constant: Formulae

For dispersion formulae for gases, *see* Table 2

$$V = \frac{C}{\lambda}\left(n - K\lambda\frac{dn}{d\lambda}\right)$$; visible spectrum (14)

$$V = \frac{C_1}{n\lambda^2}\left[\left(\frac{\lambda^2}{\lambda^2 - \lambda_1^2}\right)^2 + K_1\right]$$; visible and ultra-violet (21); n = index of refraction

Unit of λ, $\lambda_1 = 0.001$ mm $= 1\mu = 10^4$ Å; K and K_1 are dimensionless

	K	Lit.
Creosote	35	(13)
Glass:*		
Crown	28.90	(13)
Flint (1)	8.01	(13)
Flint (2)	9.20	(13)
Flint (3)	13.03	(13)
Fe_2Cl_6†	−122	(1)

	K	λ_1	K_1	Lit.
NaCl‡	26.39			(14)
$TiCl_4$	−715.82			(2)
H_2O	77.65	0.12604	0.7381	(21, 23)
CS_2	15	0.1804	0	(14, 21)
C_6H_6		0.1902	0.6069	(21)
m-C_8H_{10}		0.1886	0.64219	(21)
α-$C_{10}H_7Br$		0.2563	1.1265	(21)

* For crown, $d = 2.55$; flint (1), (2), (3), $d = 5.32$, 4.39, 4.08, respectively.
† Aqueous solution, 33% Fe_2Cl_6.
‡ Range covered is $0.214\mu \leq \lambda \leq 0.644\mu$.

Table 12.—Dispersion of Verdet Constant for Pure Gases

For dispersion formulae, *see* Table 11. Temperature (t) in °C; Unit of $\lambda = 1$ Å, $p = 1A_n$

λ	O_2 (30)			H_2 (30)			CO_2 (30)		
	t	p	V/V_1	t	p	V/V_1	t	p	V/V_1
4358	17.4	83.8	1	18.6	93.85	1			
4047	17.2	83.8	1.10	18.3	93.9	1.18	16.1	25.35	1
3665	17.5	83.25	1.31	18.7	90.0	1.45	17.5	27.3	1.22
3130	16.9	84.9	1.795	17.9	88.1	2.14	17.5	27.3	1.79
2805	17.4	82.5	2.24	19.8	75.2	2.83	17.2	27.2	2.27
2755	17.1	41.3	2.31						
2654	16.5	41.05	2.50	19.7	75.5	3.29	16.5	27.2	2.61
2535				20.9	74.9	3.67	16.2	27.3	2.95
2482				20.5	75.0	3.905			
2399				19.3	74.7	4.27			
2378				19.3	74.8	4.37			

Table 13.—Dispersion of Verdet Constant: Pure Substances

See also Table 14. For dispersion formulae, *see* Table 11
Unit of $\lambda = 1\text{m}\mu = 10$ Å; $\lambda_D = 589.3\text{m}\mu = 5893$ A

N_2* (10); $t = -195.5$°C		O_2* (10); $t = -182.5$°C	
λ	V/V_D	λ	V/V_D
6260	0.871	6260	0.897
6100	0.935	6100	0.848
5780	1.043	5780	1.062
5461	1.172	5461	1.103
5010	1.355	5010	1.118
4359	1.860	4359	1.319

*Liquid.

CO_2* (8); t = 26°C

λ	V/V_D
6260	0.866
5461	1.200
4359	2.130

CS_2* (21)

670.8	0.72572
495.8	1.5432
432.6	2.2407
414.4	2.5377
404.6	2.7206

(25)

546.1	1.197
436.0	2.140

CS_2 (8)

626.0	0.863
578.0	1.170
546.1	1.221
435.9	2.190

H_2O, *see* Table 1

SO_2* (8); t = −10°C

6260	0.910
6100	0.942
5461	1.151
4359	1.795

$TiCl_4$, Titanium tetrachloride; *see* Table 4

CH_3Cl, Methyl chloride (8) t = 18°C

626.0	0.897
546.1	1.168
435.9	1.957

CH_4O, Methyl alcohol (10)

656	0.81
578	1.04
546	1.155
492	1.47
436	1.915
366	2.80
334	3.45
254	7.3

$C_2H_4O_2$, Acetic acid (25)

546.1	1.175
436.0	1.924

C_3H_6O, Acetone (25)

546.1	1.181
436.0	1.942

C_3H_8O, *n*-Propyl alcohol (25)

546.1	1.192
436.0	1.946

$C_4H_8O_2$, Isobutyric acid (25)

546.1	1.162
436.0	1.930

$C_4H_{10}O$, Ethyl ether (10)

656	0.80
576	1.04
546	1.165
492	1.47
436	1.91

* Liquid.

$C_4H_{10}O$, Isobutyl alcohol (25)

λ	V/V_D
546.1	1.174
436.0	1.923

$C_5H_{10}O_2$, Isovaleric acid (25)

546.1	1.176
436.0	1.917

C_6H_6, Benzene (21)

452.9	1.8785
404.6	2.5301
363.1	3.4541
330.6	4.6650
310.0	5.8680

$C_6H_{10}O_5$, Dimethyl malate (active) (11)

710.0	0.707
546.1	1.192
491.6	1.468
435.6	1.856

$C_6H_{12}O_2$, Methyl valerate (active) (11)

710.0	0.670
546.1	1.184
491.6	1.467
435.9	1.849

C_6H_{14}, Hexane (10)

656	0.78
578	1.04
546	1.175
492	1.48
436	1.93

C_8H_{10}, *m*-Xylene (21)

670.8	0.75117
495.8	1.5034
452.9	1.8738
404.6	2.5227
363.1	3.4285

$C_8H_{14}O_5$, Diethyl malate (11) (active)

710.0	0.666
546.1	1.173
435.9	1.915

$C_{10}H_{14}O$, Carvone (active) (11)

710.0	0.715
546.1	1.168
491.6	1.526

$C_8H_{14}O_6$, Diethyl tartrate (active) (11)

710.0	0.670
546.1	1.158
453.9	1.895

$C_{10}H_7Br$, α-Bromonaphthalene (21)

670.8	0.74025
495.8	1.6035
452.9	2.1062
404.6	3.1205
373.5	4.4230

$C_{10}H_{16}$, Limonene (10)

λ	V/V_D
656	0.79
578	1.04
546	1.18
492	1.49
436	1.97

$C_{10}H_{16}$, Limonene (active) (11)

710.0	0.707
546.1	1.182
491.6	1.507
435.9	1.993

$C_{10}H_{16}$, α-Pinene (10)

656	0.795
578	1.04
546	1.175
492	1.48
436	1.94
366	2.95
313	4.10

$C_{10}H_{16}$, β-Pinene (10)

656	0.79
578	1.04
546	1.18
492	1.49
436	1.97
366	3.09
313	4.31

$C_{10}H_{16}$, Turpentine (active) (11)

710.0	0.655
546.1	1.179
491.6	1.503
435.9	1.961

$C_{10}H_{16}O$, Camphor (10)

656	0.80
578	1.04
546	1.17
492	1.505
436	1.94
366	2.95
334	3.66
254	7.7

$C_{10}H_{16}O$, Pulegone (active) (11)

710.0	0.681
546.1	1.185
491.6	1.482

$C_{10}H_{17}Cl$, Pinene hydrochloride (10)

λ	V/V_D
656	0.79
578	1.04
546	1.17
436	1.95

$C_{10}H_{18}O$, Borneol (10)

656	0.79
578	1.04
546	1.17
492	1.48
436	1.945

$C_{10}H_{18}O$, Citronellal (active) (11)

710.0	0.661
546.1	1.174
491.6	1.475
435.6	1.916

$C_{10}H_{18}O$, Menthone (active) (11)

710.0	0.691
546.1	1.181
491.6	1.450
435.9	1.937

$C_{10}H_{18}O$, Pinene hydrate (10)

656	0.79
578	1.04
546	1.18
492	1.48
436	1.95
404	2.33
366	2.98
313	4.30
280	5.75
265	6.60
253	7.68

$C_{10}H_{18}O_6$, Dipropyl tartrate (active) (11)

710.0	0.680
546.1	1.173
491.6	1.442
435.9	1.899

CCl_4, Carbon tetrachloride (25)

546.1	1.182
436.0	1.948

TABLE 14.—DISPERSION OF VERDET CONSTANT: PURE ORGANIC SUBSTANCES [16]

Cf. Table 13; numbers in body of table are values of V/V_{Hg}; λ_{Hg} = 5461 Å

Formula	Name	λ = 6708	6438	5893	5086	4800	4678	4359 Å
CS_2	Carbon disulfide	0.624	0.686	0.836	1.190	1.376	1.464	1.764
CH_2O_2	Formic acid	0.647	0.708	0.852	1.164	1.322		1.635
CH_4O	Methyl alcohol	0.645	0.707	0.851	1.164	1.315	1.386	1.624
$C_2H_4O_2$	Acetic acid	0.648	0.698	0.851	1.163	1.331		1.631
C_2H_6O	Ethyl alcohol	0.638	0.708	0.849	1.166	1.318	1.393	1.626
C_3H_6O	Allyl alcohol	0.641	0.700	0.847	1.177	1.332		1.672
$C_3H_6O_2$	Propionic acid	0.648	0.711	0.856	1.165	1.320		1.635
C_3H_8O	*n*-Propyl alcohol	0.642	0.713	0.850	1.163	1.321		1.629
C_3H_8O	Isopropyl alcohol	0.642	0.702	0.850	1.163	1.320		1.634
$C_4H_8O_2$	*n*-Butyric acid	0.645		0.853				1.634
$C_4H_8O_2$	Isobutyric acid	0.646		0.849				1.633
$C_4H_{10}O$	*n*-Butyl alcohol	0.649	0.707	0.849	1.168	1.328		1.637
$C_4H_{10}O$	Isobutyl alcohol	0.648	0.699	0.846	1.162	1.321		1.635
$C_4H_{10}O$	*sec.*-Butyl alcohol	0.645	0.713	0.850	1.164	1.309	1.391	1.635
$C_4H_{10}O$	*tert.*-Butyl alcohol	0.643	0.704	0.852	1.166	1.328		1.645
$C_5H_{10}O_2$	Isovaleric acid	0.651	0.702	0.848	1.165	1.324		1.636
$C_5H_{12}O$	Isoamyl alcohol	0.650	0.709	0.852	1.169	1.325		1.634
$C_5H_{12}O$	*act.*-Amyl alcohol	0.647		0.850				1.641
$C_5H_{12}O$	*sec.*-Amyl alcohol	0.651		0.852				1.636
$C_5H_{12}O$	*tert.*-Amyl alcohol	0.651	0.703	0.852	1.165	1.325		1.643
C_6H_{14}	*n*-Hexane	0.647	0.710	0.851	1.168	1.318		1.636
$C_6H_{14}O$	Methylisobutyl carbinol	0.650		0.850				1.644
$C_6H_{14}O$	*sec.*-Hexyl alcohol	0.647	0.705	0.852	1.165	1.321		1.639
$C_7H_{16}O$	*n*-Heptyl alcohol	0.644	0.708	0.855	1.162	1.320		1.635
$C_7H_{16}O$	*sec.*-Heptyl alcohol	0.648		0.849				1.639
$C_8H_{10}O$	Phenylmethyl carbinol	0.624	0.685	0.839	1.184	1.363		1.739
C_8H_{18}	*n*-Octane	0.650	0.706	0.850	1.168	1.325		1.634
$C_8H_{18}O$	*n*-Octyl alcohol	0.647	0.705	0.851	1.166	1.320		1.636
$C_8H_{18}O$	*sec.*-Octyl alcohol	0.642	0.705	0.849	1.163	1.320	1.394	1.635
$C_9H_{12}O$	Phenylethyl carbinol	0.634	0.689	0.835	1.181	1.362	1.451	1.731
$C_9H_{20}O$	Methylheptyl carbinol	0.649		0.849				1.635
$C_9H_{20}O$	Ethylhexyl carbinol	0.644	0.703	0.853	1.165	1.322		1.634
$C_{10}H_{22}O$	Methyloctyl carbinol	0.642		0.848				1.636
$C_{11}H_{24}O$	Methylnonyl carbinol	0.645		0.848				1.638
$C_{12}H_{26}O$	Methyldecyl carbinol	0.644		0.849				1.639

TABLE 15.—DIFFERENTIAL LAG IN APPEARANCE OF FARADAY EFFECT [1]

If $l[l_s]$ = time that elapses between the application of the field and the appearance of the rotation in the substance [in CS_2], $\Delta \equiv l - l_s$. Unit of Δ = 1 mμ sec = 10^{-9} sec; uncertainty in $\Delta \equiv \pm 0.3$ mμ sec.

	Substance	Δ
CS_2	Carbon disulfide	0
H_2O	Water	1.1
CCl_4	Carbon tetrachloride	1.1
C_6H_6	Benzene	1.9
C_8H_{10}	Xylene	2.1
$CHCl_3$	Chloroform	2.4
C_7H_8	Toluene	2.5
$C_5H_{12}O$	Amyl alcohol	4.0
$CHBr_3$	Bromoform	4.1

LITERATURE

(For a key to the periodicals see end of volume)

(1) Beams and Allison, *2*, **29**: 161; 27. (2) Becquerel, *6*, **12**: 5; 77. (3) Becquerel, *6*, **19**: 90; 80. (4) Becquerel, *51*, **4**: 437; 85. (5) Bichat, *51*, **8**: 204; 79. **9**: 275; 80. (6) du Bois, *8*, **51**: 537; 94. (7) Borel, *149*, **16**: 157; 03. (8) Chaudier, *34*, **156**: 1008, 1529; 13. (9) Cornu and Potier, *34*, **102**: 385; 86.

(10) Darmois, *6*, **22**: 247, 295; 11. (11) Herngrist, *Diss.*, Upsala, 1914. *10*, **4**: 678; 22. (12) Humburg, *7*, **12**: 401; 93. (13) Ingersoll, *2*, **9**: 257; 17. (14) Joubin, *6*, **16**: 78; 89. (15) Lowry, *4*, **105**: 81; 14. (16) Lowry and Dickson, *4*, **103**: 1067; 13. (17) Moureu, Müller and Varin, *6*, **2**: 269; 14. (18) Perkin, *4*, **45**: 421; 84. **49**: 777; 86. **51**: 362; 808; 87. **53**: 561, 695; 88. **55**: 680; 89. **59**: 981; 91. **61**: 800; 92. **63**: 57, 488; 93. **65**: 20, 402, 815; 94. **67**: 255; 95. **69**: 1025; 96. (19) Perkin, *4*, **81**: 177, 292; 02.

(20) Quincke, *8*, **24**: 606; 85. (21) Richardson, *3*, **31**: 232; 16. (22) Rodger and Watson, *62*, **186**: 621; 95. (23) van Schaik, *18*, **21**: 406; 87. (24) Schönrock, *7*, **11**: 753; 93. (25) Schwers, *186*, **1912**: 719. (26) Siertsema, *64V*, **2**: 31; 94. **3**: 230; 95. **4**: 317; 96. **5**: 132; 97. *18*, **6**: 825; 01. *168*, Nos. **7, 15, 24, 31, 73.** (27) Siertsema, *18*, **5**: 447; 00. *168*, No. **62.** (28) Siertsema, *168*, Nos. **90, 91**; 04. *Boltzmann Festschrift*, p. 780; 04. *64P*, **6**: 760; 04. (29) Siertsema, *64P*, **18**: 101; 15.

(30) Sirks, *64P*, **15**: 773; 12. *63*, **14**: 336; 13. (31) Thouvenot, *Thesis*, Nancy, 1910. (32) Vecela-Guerdjikowa, *Thesis*, Nancy, 1910. (33) Verdet, *6*, **41**: 370; 54. **43**: 37; 55. **52**: 129; 58. **69**: 415; 63.

ROTATION AT REFLECTION—KERR EFFECT

A. Cotton and M. Cau

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When plane polarized light is incident upon a reflecting surface, magnetizing the reflecting material produces, in general, a rotation of the plane of polarization of the reflected light, and under certain conditions introduces a circularly polarized component. The magnitudes of the several effects depend upon the intensity of magnetization (I) of the substance and apparently not upon either the temperature or the intensity of the magnetic field (H), except as these affect I; they vary from specimen to specimen, and not infrequently depend upon the particular region under study. Three cases are distinguished: (1) Polar reflection, I being normal to the reflecting surface; (2) longitudinal (or meridional) reflection, I being parallel to reflecting surface and to the plane of incidence; (3) transverse (or equatorial) reflection, I being parallel to reflecting surface and perpendicular to plane of incidence. If r = rotation produced by increasing the magnetization from zero to I, then for polar reflection, normal incidence, $r = KI$, where K depends only upon the reflector and the wave-length (λ) of the light; K is Kerr's constant; r is considered positive if it is in the direction of the Amperian currents producing I.

When a key number precedes the symbol or name of a substance it refers to Table 1 where such information as is available regarding the specimen is given.

Table 1.—Kerr Constant (K_λ) and Rotation (r_m) at Saturation: Polar Reflection, Normal Incidence, One Wave-length

H = intensity of magnetic field; the substance is magnetically saturated (= satd.) unless marked "uns."; unit of λ = 1 mμ = 10^{-6} mm = 10 Å; of K_λ = 0.001 minute of arc per cgsm unit of I; of r_m = 1′; of H = 1 kilogauss = 1000 gauss

Key	Substance	Remarks	Source	H	λ	K_λ	r_m	Lit.
1	Fe	Electrolytic iron	Gumlich	40	530.0	−13.5	−22.68	(1)
2	Fe	Electrolytic, on platinized glass		13	520		−11.4	(13)
3	Fe	Cathode deposit (vacuum)		13.2	520		− 7.8	(13)
4	Fe	Distilled on glass, brilliant		20.5	588		−18.1	(2)
5	Fe	Distilled on glass, dull		15.8	588		−17.9	(2)
6	Fe	Pure	Kahlbaum	22.9	520		−19.74	(3)
7	Fe	Pure cast; no S, Si, Mn	Weiss		530.0	−11.3	−18.97	(1)
8	Fe	Swedish; 0.22% C; tr. of P, Si, Mn	Kohlswa	40	546.1	−12.3	−20.59	(1)
9	Fe	Swedish commercial		20.4	520		−19.2	(3)
10	Fe, Ce	Ferrocerium		uns.	530		− 6.22*	(9)
11	Fe_2O_3.FeO	Magnetite	Griesheim	satd.	450.0	− 4.6	− 1.89	(1)
12	Fe_2O_3.FeO	Magnetite; artificial, compressed powder	Weiss	satd.	450.0	− 2.7	− 1.10	(1)
13	Fe_2O_3.FeO	Magnetite; natural	DuBois	12	450.0	− 5.2	− 2.00	(1)
14	Fe_2O_3.FeO	Magnetite (Pfitschthal)		16.4	440		− 1.44	(3)
15	Fe_2O_3.FeO	Magnetite (Traversella)		15.8	439		− 2.1†	(2)
16	Fe_2O_3.FeO	Magnetite		10	900		+ 3	(4)
17	Fe_2O_3.ZnO	Franklinite	DuBois	7.5	450.0	− 8.0	− 1.19	(1)
18	Fe_2O_3.ZnO	Franklinite (New Jersey)		satd.	530		+ 1.2	(10)
19	Fe_2O_3.CuO	Cuproferrite	DuBois	7.5	477.0	+ 6.3	+ 1.68	(1)
20	Fe_2O_3.CuO	Cuproferrite	Hilpert	10.15	477		+ 1.75	(8)
21	Fe_2O_3.CoO	Cobalt ferrite	Hilpert	satd.	530		− 0.6	(10)
22	Fe_2O_3.CaO	Calcium ferrite	Hilpert	satd.	530		+ 0.2	(10)
23	Fe_7S_8	Pyrrhotite (Brazil)		satd.	Any		+ 1	(9)
24	Fe_3C	Cementite	Hilpert	satd.	530		−26.45	(9)
25		Steel	Schmidt and Haensch	20	588		−22.7	(2)
26		Steel		19.2	520		−20.88‡	(3)
27	Fe_2Si	Ferrosilicon; Fe_2Si = 30 At. %§	Tammann	satd.	530		−16.75	(10)
28	Fe_2Co		Weiss	20	530.0	−14.95	−27.64	(1)
29	Fe, Co, Sb	66Fe + 30Co + 4Sb	DuBois	satd.	530.0	−14.7	−23.66	(1)
30	Fe, Ni	25.4% Ni	Krupp	16.3	589		−17.29*	(8)
31	Fe, Ni	27% Ni	Weiss	16.8	589		−15.92*	(8)
32	Fe_2Ni	36% Ni	Weiss	20	530.0	−17.2	−15.05	(1)
33	Fe, Ni	36% Ni (Invar)	Commentry-Fourchambault	14.5	574	−15.6	−13.65	(8)
34	Fe, Ni	36% Ni (Invar)	De Haën	19.8	520		−13.86	(3)
35	Fe, Mn	92.2Fe + 7.8Mn	Gumlich	39	530.0	−14.8	−19.70	(1)
36	Fe, Mn	89.6Fe + 10.4Mn	Gumlich	satd.	530.0	−15.1	−13.16	(1)
37	Co	Electrolytic	Merck	34	530.0	−14.7	−20.58	(1)
38	Co	Pure	Kahlbaum	22.1	520		−21.18	(3)

48.—(*Continued*)

λ	r_m	e
640	− 8.22	+0.23
660	− 8.40	+0.24
49 Ni (2); H = 17.7		
439	− 9.3	−0.86
471	− 8.9	−0.44
505	− 8.2	−0.25
546	− 8.1	−0.15
588	− 8.3	−0.04
623	− 8.5	+0.14
656	− 8.7	+0.27

55 Cu, Mn, Al (2); H = 16.8

λ	r_m	e
439	+ 0.05	−0.66
471	− 1.0	−0.64
505	− 1.5	−0.64
546	− 2.1	−0.42
588	− 2.3	−0.20
623	− 2.2	−0.10
656	− 2.1	0.00

* Reflecting surface is parallel to face of octahedron. † Quenched.

Table 4.—Polar Reflection, Plane Polarized Light, Oblique Incidence, Fe (11)

Filtered sunlight, sensibly homogeneous. No statement regarding composition and source of Fe, nor of the values of λ, H, and I. Probably the Fe was magnetically saturated. i = angle of incidence. $R_\parallel[R_\perp]$ = rotation when plane of vibration (electric vector) of incident light is parallel [perpendicular] to plane of incidence. If the plane of vibration of the incident light makes a characteristic angle α_i with the plane of incidence, the reflected light is plane polarized and its plane of vibration makes an angle α_r with plane of incidence. Angles are positive when measured in the direction of the Amperian currents which produce the field. Unit of i = 1°; of $R_\parallel$, $R_\perp$, α_i and α_r = 1′.

i	$-2R_\parallel$	$-2R_\perp$	$2\alpha_i$	$2\alpha_r$
6.0	33	33		
15.5	33	32.4		
22.2	33.5	31.2		
36.4	36	30		
44.3	45	28.8	−19.8	+57.2
56.9	52.8	24.6	−10.2	+57.1
68.1	51	19.2	+ 3.0	+44.8
76.6	45	12	+ 7.2	+36
84.8	15	6	+13.2	+20
87.2	6	1.5		

i*	$-2R_\parallel$	$-2R_\perp$	α_i	α_r
40.9	59.9	38	−46.8	+114.6
47.9	60.2	34	−29.4	+ 95.2
54.9	61.2	29.6	−16	+ 80
63.0	60.9	24.1	− 1.2	+ 61.9
67.8	59.2	20.5	+ 5.8	+ 54.8
72.8	51.6	16.3	+11.2	+ 47.4
76.6	38	11.9	+13.4	+ 39.4
82.6	12	5.2	+17.6	+ 29.2

* H is greater than for data in above table.

Table 5.—Longitudinal Reflection, Plane Polarized Light, Oblique Incidence

I is parallel to surface and to plane of incidence. No statement regarding composition and source of Fe, nor of the values of λ, H, and I. Probably the Fe was magnetically saturated. For notation, *see* Table 4. Three specimens.

Fe (12)

i	$2R_\parallel$	$2R_\perp$
11	+ 2.3	−2.5
20	+ 4	−5
30	+ 6 7	−6.6
35	+ 7.6	
40	+ 8	−6.7
45	+ 9	
50	+10	−9
55	+10.5	

Fe.—(*Continued*)

i	$2R_\parallel$	$2R_\perp$
60	+11	−9
65	+ 8.7	
70	+ 6.5	−7.9
75	+ 4.5	
78.9	0	−6.7
80	− 1	
85	− 3	−3

Steel (7)

i	$2R_\parallel$	$2R_\perp$
19.0	+ 2.7	−4.8
29.9	+ 7.3	−4.5
39.5	+ 7.7	−6.6
50.1	+ 6.9	−7.7
61.3	+ 7.5	−8.0
65.0	+ 8.7	−9.4
70.0	+ 8.1	−7.1
75.0	+ 6.8	−6.0
80.3	+ 2.6	
82.0	− 2.3	−4.3
85.2	− 1.9	−3.9

Ni, Electrolytic Ni on steel (7)

i	$2R_\parallel$	$2R_\perp$
20.0	0.0	
30.1	+ 1.8	−1.7
40.0	+ 1.4	−2.7
50.0	+ 0.3	−4.7
61.5	− 0.7	−4.2
65.3	− 2.2	−3.8
75.0	− 1.9	−1.1

Table 6.—Transverse Reflection, Plane Polarized Light, Oblique Incidence (6)

I is parallel to surface and perpendicular to plane of incidence. When I = 0, the intensity of that component of the reflected light which is polarized in plane of incidence is equal to that of the component polarized perpendicular thereto, if the plane of polarization of the incident light makes an angle θ with the plane of incidence. When I is not zero, the equality occurs when the angle is $\theta + \eta$. i = angle of incidence. The key numbers refer to Table 1 where the material is more fully defined. Tabulated values = 2η; unit of η = 1′; of λ = 1mμ = 10^{-6} mm = 10 Å.

λ	590	730	910	λ	1210	1650	2100
i	**26** Fe or steel			i	**26** Fe or steel		
18.6	+ 3.77			19.8	+ 3.0	+ 0.4	0.0
19.6		+ 3.9	+ 4.3	41.9	+ 3.9	+ 0.5†	− 1.2*
40.9	+ 9.42*	+ 9	+11.0	66.8	+ 5.6†	+ 0.4	− 4.4
66.8	+17.80†	+16	+14.2	70		− 3.7	
74.6	+17.11	+15.7‡	+12.0‡	74.5			− 7.5
79.9	+ 9.87	+ 5.2	+ 1.5	75.0	+ 4.0	− 4.0	
80.0		+ 5.6†	+ 2.5	80.0	− 4.0	− 6.4	−11
83.4	+ 4.88		− 5.0	83.5	−11.0	−16.0	−17.1
86.4	+ 1.00	− 3.0	− 6.2	85	− 9.6		
87.3		− 2.3		86.8	−12.9		−16.8§
88.3		− 2.5	− 5.0	88.3	− 7.5‖	−13.8	−16.2

λ	590	740	930	λ	1240	1700	2130
i	**39** Co			i	**39** Co		
18.0		+1.3	+1.1	18.0		+ 0.2	0
18.6	+1.60			29.8	+ 0.8		
40.8	+3.98			41.8	+ 1.5	+ 1.2	+ 1.0
41.8		+4.0	+3.0	56.8	+ 1.8	+ 1.0	+ 0.8
56.8		+5.6	+4.7	66.9		+ 1.5	+ 0.3
66.9	+7.30			72.5	+ 1.6		
74.6	+6.56			75	+ 0.7	− 0.5	+ 1.6
75		+5.7	+4.3	77.5	− 0.9		
83.4	−1.00			80	− 3.9		
83.5		−1.7	−6.2	83.5		− 9.2	− 5.8
85			−8.6	85	−12.5	−13.4	
86.4	−2.07			86.5		−13.0	−14.5
86.5		−3.5	−7.8	88	− 8.9		

* i is 0.1° < tabulated. † i is 0.1° > tabulated. ‡ i is 0.2° > tabulated.
§ i is 0.6° > tabulated. ‖ i is 0.3° < tabulated.

λ	590	λ	740	1240	2120
i	**49** Ni	i	**49** Ni		
40.8	+1.24	20	−0.3	−0.7	−1.2
66.9	+0.70	60.5	−0.9	−3.6	−3.1
79.9	−1.41	67	−1.0	−5.4	−3.9
83.4	−2.09	74.8	−2.7	−5.9	−5.6

TABLE 6.—(*Continued*)

λ	590	λ	740	1240	2120
i	49 Ni	*i*	49 Ni		
86.4	−1.40	80	−4.5	−7.9	−6.3
		85	−3.9	−7.3	−5.8
		87.5	−2.3	−5.9	−4.1
		88.6	−1.3	−4.0	−2.3

LITERATURE

(For a key to the periodicals see end of volume)

(1) Barker, *67*, **29**: 1; 26. (2) Dziewulski, *63*, **13**: 642; 12. (3) Foote, *2*, **34**: 96; 12. (4) Ingersoll, *3*, **11**: 41; 06. (5) Ingersoll, *3*, **18**: 74; 09. (6) Ingersoll, *2*, **35**: 312; 12. (7) Kundt, *8*, **23**: 228; 84. (8) Loria, *8*, **38**: 889; 12. (9) Martin, *8*, **39**: 625; 12.
(10) Martin, *8*, **55**: 561; 18. (11) Righi, *6*, **9**: 65; 86. (12) Righi, *6*, **10**: 200; 87. (13) Skinner and Tool, *3*, **16**: 833; 08.

MAGNETOSTRICTION AND ALLIED EFFECTS

S. R. WILLIAMS

Magnetostriction comprises that group of magnetic phenomena in which the application of a magnetic field is accompanied by changes in dimensions of the body, and those reciprocal relations in which the application of a stress is accompanied by changes in magnetic properties. The names of the various phenomena, and the more important or interesting papers treating of them, are as follows:

Length Effects

Joule effect—change in length due to a magnetic field (3, 4, 7, 8, 13, 20, 24, 27, 35, 36, 39, 46, 59, 62).

Villari effect—change in magnetization due to a longitudinal stress (15, 26, 32, 52, 54, 60).

Transverse Joule effect—change in dimensions normal to magnetic field (9, 20, 27, 59).

Transverse Villari effect—change in magnetic properties normal to stress.

Wertheim effect—bending due to a magnetic field (17, 34, 55).

Converse of Wertheim effect—magnetic properties changed by bending.

Change in Young's modulus due to a magnetic field (12, 25, 47, 48, 49).

Circular Effects

Wiedemann effect—twist due to interaction of longitudinal and circular fields (6, 16, 29, 39, 43, 56, 58).

Wiedemann effect, No. 2—longitudinal magnetization produced by twisting circularly magnetized rod (39, 56).

Wiedemann effect, No. 3—circular magnetic field produced by twisting longitudinally magnetized rod (37, 39, 56).

Coefficient of rigidity changed by magnetization (12, 25, 47, 48, 49).

Mechanically twisted rods twisted by a circular or longitudinal magnetic field.

Volume Effects

Barrett effect—volume change due to magnetization (4, 11, 30, 38).

Nagaoka and Honda effect—changes in magnetic properties due to hydrostatic pressure.

Change in bulk modulus due to a magnetic field (12, 25, 47, 48, 49).

Allied Effects

Change in electrical resistance due to a magnetic field (19, 31, 40, 42, 57); *see* p. 414.

Change in thermoelectric emf's due to a magnetic field (1, 45, 50, 51); *see* p. 213.

Emf due to magnetization (10, 14, 41, 44).

Change in frequency of a tuning fork when subjected to a magnetic field (28, 33).

Sounds produced by magnetization (2, 3, 22, 53, 61, 63).

The Joule and the Villari are the fundamental magnetostrictive effects, the others being merely special cases of them or of the superposition of two or more of them. The changes in the elastic moduli are to be regarded as the result of the changes in dimension which result from the Joule effects.

Owing to the many factors which affect magnetostrictive phenomena—heat treatment, stress, hardness, impurities, previous magnetic history, etc., which factors are unknown in most of the work which has been done—it is extremely difficult to estimate the accuracy of the data. Those given in the following tables were selected as illustrative, rather than as exact numerical data applicable to definite materials; and the materials represented are those which will probably be most frequently needed for comparative studies. Much additional information will be found in the papers already listed.

In careful work, the Joule effect can be determined with an accuracy of 4% to 5% for iron, and with a somewhat lower accuracy (4% to 6%) for other materials; the Wiedemann effect can be observed to a higher precision; the Barrett effect is extremely difficult to measure; 10% is a fair average of probable error.

If at the center of a bar the magnetic field is H-NI, where H is the applied field and I is the intensity of magnetization of the bar, N is called the *demagnetizing factor*. Most data are expressed in terms of H-NI; exceptions are suitably indicated.

Table 1.—Longitudinal Joule Effect

Tabular values = A; $A \times 10^{-6} = (l - l_0)/l_0$; l, l_0 = length of specimen in field = H, field = 0. Unit of H = 1 cgsm = 1 gauss; of one constituent (C, Ni, or Co) of alloy = 1 %; t = centigrade temperature

Fe, C, Iron-carbon alloys [13]

H \ C	0.60	0.74	0.89	0.98	1.18	1.37	H \ C	0.60	0.74	0.89	0.98	1.18	1.37
20	1.24	0.75	0.2	0.36	0.87	0.70	600	−4.88	−4.09	−3.82	−4.24	−3.68	−3.65
40	1.68	1.24	0.5	0.77	1.38	1.40	700	−5.52	−4.60	−4.34	−4.73	−4.25	−4.14
60	1.76	1.41	0.65	0.92	1.44	1.53	800	−5.86	−4.99	−4.67	−5.13	−4.65	−4.52
80	1.74	1.34	0.67	0.87	1.37	1.47	1000	−6.28	−5.53	−5.24	−5.72	−5.36	−5.13
100	1.56	1.17	0.57	0.72	1.22	1.26	1200	−6.65	−5.84	−5.62	−6.12	−5.86	−5.58
200	0.10	−0.04	−0.34	−0.42	0.07	−0.06	1400	−6.96	−6.02	−5.90	−6.38	−6.21	−5.87
300	−1.46	−1.43	−1.46	−1.79	−1.20	−1.23	1600	−7.24	−6.09	−6.08	−6.56	−6.42	−6.01
400	−2.88	−2.54	−2.38	−2.83	−2.24	−2.29	1800	−7.53	−6.15	−6.23	−6.74	−6.57	−6.16
500	−4.03	−3.43	−3.20	−3.61	−3.04	−3.04							

Fe, Soft* iron [24]

H \ t	−186	8.4	168	319
50	1.86	1.60	1.06	2.00
100	3.30	3.20	3.20	4.53
150	2.93	3.03	3.40	4.78
200	2.10	2.40	3.10	4.74
300	−0.30	0.55	1.75	4.21
400	−2.56	−1.15	0.40	3.68
500	−4.50	−2.63	−0.72	3.20
600	−6.07	−3.90	−1.67	2.80
700	−7.25	−4.95	−2.22	2.50
800	−8.20	−5.70	−2.63	2.30
900	−9.14	−6.05	−3.00	2.18

* Demagnetizing factor = 0.0683, not corrected for; H = applied field.

Fe, Ni, Iron-nickel alloys [21]

H \ Ni	0	9.2	18.5	29.1	36.9	50	70	73.8	83	92.3
50	2.63	2.14	1.86	2.54	12.10	12.20	7.23	3.00	−5.75	−10.75
100	2.82	4.17	3.72	3.68	15.93	16.40	9.10	3.30	−6.38	−17.30
150	2.28	5.83	5.56	4.29	17.30	18.00	9.82	3.43	−6.65	−20.10
200	1.64	7.18	7.02	4.79	18.13	18.95	10.26	3.53	−6.81	−22.05
250	0.96	8.32	8.17	5.26	18.67	19.58	10.61	3.63	−6.92	−23.20
300	0.35	9.33	9.15	5.72	19.10	19.96	10.90	3.72	−6.98	−23.57
350	−0.18	10.23	10.03	6.17	19.45	20.30	11.13	3.78	−7.00	−23.75
400	−0.63	11.02	10.80	6.63	19.80	20.63	11.29	3.83	−7.02	−23.92
450	−1.00	11.74	11.50	7.08	20.10	20.95	11.42	3.88	−7.04	−24.10
500	−1.31	12.41	12.12	7.53	20.35	21.26	11.52	3.91	−7.05	−24.27
550	−1.57	13.45	12.71	7.98	20.60	21.58	11.60	3.95	−7.05	−24.45

Ni, Nickel* [24]

H \ t	−186	17.2	197	376
50	− 6.75	− 9.60	− 7.43	−0.19
100	−15.53	−20.00	−13.85	−0.49
150	−20.65	−26.00	−16.92	−0.53
200	−23.80	−29.70	−18.33	−0.55
300	−27.20	−33.10	−19.52	−0.55
400	−29.75	−34.70	−20.10	−0.54
500	−32.00	−35.45	−20.50	−0.54
600	−33.80	−36.03	−20.70	−0.54
700	−35.27	−36.50	−20.90	−0.54
800	−36.44	−36.82	−21.00	−0.54
900	−37.30	−37.10	−21.02	−0.54

Fe, Co, Iron-cobalt alloys [21]

H \ Co	0	10	20	30	40	50	70	80	90	100
50	2.97	10.45	13.85	21.40	28.70	17.00	20.70	4.36	−5.40	− 2.55
100	3.10	13.30	17.16	27.10	37.00	27.00	34.60	4.76	−6.58	− 4.60
150	2.62	14.55	19.00	29.56	40.40	33.90	43.55	4.00	−6.65	− 6.07
200	2.00	15.33	20.06	30.75	42.23	39.00	49.72	2.83	−6.50	− 6.96
250	1.20	15.84	20.60	31.21	43.60	43.10	54.30	1.44	−6.22	− 7.64
300	0.30	16.10	20.87	31.36	44.47	46.20	57.35	0.06	−5.87	− 8.16
350	−0.46	16.20	20.95	31.44	44.99	48.50	59.67	−1.26	−5.52	− 8.60
400	−1.07	16.16	20.92	31.49	45.37	50.25	61.40	−2.25	−5.13	− 9.03
450	−1.56	16.06	20.82	31.49	45.62	51.62	62.78	−3.20	−4.70	− 9.45
500	−1.98	15.91	20.69	31.49	45.80	52.80	63.83	−4.10	−4.25	− 9.83
550	−2.32	15.78	20.58	31.50	46.00	53.85	64.67	−4.96	−3.78	−10.21

Cu, Mn, Al, Heusler alloys† [18]

H	I	II	III	IV
50	0.990	0.184	0.700	0.646
100	1.270	0.223	1.030	0.784
150	1.405	0.249	1.137	0.867
200	1.505	0.263	1.169	0.929
250	1.577	0.266	1.191	0.964
300	1.627	0.269	1.213	0.981
350	1.665	0.272	1.234	0.989
400	1.692	0.275	1.255	0.997
450	1.710	0.278	1.274	1.040
500	1.723	0.280	1.294	1.011
550	1.734	0.283	1.313	1.016

* Demagnetizing factor = 0.0801, not corrected for; H = applied field.

† I = 64.49Cu, 20.39Mn, 13.25Al; II = 70.14Cu, 18.03Mn, 10.03Al; III = 59.43Cu, 22.60Mn, 14.50Al; IV = 65.22Cu, 19.76Mn, 11.13Al.

Table 2.—Joule Effect: Magnetite Crystal [20]

A_2, A_3, A_4 = value of A along the digonal, trigonal, tetragonal axis. $A \times 10^{-6} = (l - l_0)/l_0$; l, l_0 = length in field = H, in field = 0. Unit of H = 1 cgsm = 1 gauss.

H	Longitudinal			Transverse		
	A_2	A_3	A_4	A_2	A_3	A_4
900	4.04	2.01	−0.54	− 7.60	− 2.60	0.76
1000	5.10	2.42	−0.63	− 9.75	− 3.50	0.91
1500	10.09	4.46	−1.18	−18.50	− 8.10	1.67
2000	14.35	6.37	−1.82	−25.25	−12.40	2.42
2500	17.85	8.04	−2.47	−30.55	−16.33	3.07
3000	20.93	9.40	−3.03	−35.10	−19.60	3.57
3500	23.80	10.48	−3.50	−38.70	−22.13	3.94
4000	26.57	11.34	−3.85	−41.33	−24.04	4.20
4500	29.20	12.04	−4.08	−43.20	−25.77	4.35

Table 3.—Change in Young's Modulus with Magnetic Field

E, E_0 = Young's modulus in field = H, field = 0; F = tension of specimen; ΔF = increase of F in determination of E; $(E - E_0)/E_0 = 0.01A$. Tabular values = A. Unit of F = 1 kg/cm² = 980 665 barye = 14.22 lb./in.²

Ni, Nickel [25]; 10.0°C, ΔF = 74.3

H \ F	154.0	302.1	449.8	H \ F	154.0	302.1	449.8
5	− 0.13	− 0.30	−0.10	80	−2.32	−8.18	−7.92
10	− 1.40	− 0.70	−0.23	90	−1.62	−6.35	−9.86
20	− 5.80	− 1.73	−0.67	100	−1.08	−5.00	−9.80
30	−11.30	− 3.18	−1.31	150	+0.24	−1.78	−4.44
40	−13.00	− 5.27	−2.17	200	+1.03	−1.15	−3.03
50	− 7.30	− 8.55	−3.23	300	+2.14	−0.37	−1.47
60	− 4.60	−11.85	−4.55	400	+2.40	+0.22	−0.78
70	− 3.26	−11.54	−6.10				

Fe*

H \ F	162.7
50	0.08
75	0.15
100	0.18
150	0.22
200	0.24
300	0.26
400	0.28

* Swedish iron [25]; 11.5°C, ΔF = 78.4.

Table 4.—Wiedemann Effect (φ)

The circular field is in all cases produced by the current J flowing along the geometrical axis of the specimen, which is a circular cylinder, bar or tube. H = longitudinal field which produces the twist φ. Looking in direction of H, the positive direction of φ is that of the circular field produced by J. Tabular values = φ. Unit of H = 1 cgsm = 1 gauss; J = 0.1 cgsm = 1 ampere; φ = 1″ per cm of length.

Fe, Iron bar [23]				Ni, Nickel bar [23]			
H \ J	3.12	5.26	8.86	H \ J	2.00	4.37	6.55
25	0.057	0.080	0.186	25	−0.288	−0.888	−1.243
50	0.235	0.408	0.706	50	−0.302	−1.052	−1.421
75	0.435	0.648	0.954	75	−0.217	−0.879	−1.221
100	0.466	0.688	0.941	100	−0.164	−0.733	−1.021
150	0.364	0.515	0.733	150	−0.089	−0.506	−0.755
200	0.280	0.377	0.533	200	−0.058	−0.371	−0.577
300	0.155	0.222	0.302	300	−0.026	−0.222	−0.386
400	0.106	0.151	0.186	400	−0.022	−0.164	−0.293
500	0.071	0.071	0.120	500	−0.018	−0.133	−0.244
600	0.044	0.062	0.084	600	−0.016	−0.106	−0.200
700	0.022	0.044	0.062	700	−0.013	−0.075	−0.146

Fe, C, Low carbon steel: tubes [58]

H \ J	0.52	1.00	1.50	1.50	2.00
10	0.301	0.702	1.253	0.251	0.377
20	1.332	2.682	4.436	1.255	1.757
30	1.805	3.561	5.226	1.962	2.610
40	1.499	2.924	4.493	1.862	2.534
50	1.223	2.387	3.684	1.606	2.133
60	0.978	1.959	2.964	1.330	1.752
70	0.771	1.583	2.362	1.104	1.418
80	0.616	1.285	1.917	0.916	1.129
90	0.499	1.063	1.575	0.763	0.898
100	0.405	0.877	1.296	0.627	0.713
150	0.065	0.277	0.382	0.070	0.109
200	−0.095	−0.018	+0.012	−0.100	−0.031
250	−0.160	−0.150	−0.217	−0.109	−0.105
	d_0* = 0.1600 cm			0.2447 cm	
	d_i* = 0.0794 cm			0.0970 cm	
	l* = 79.8 cm			79.7 cm	

* d_0, d_i = outer, inner diameter of tube, l = free length of tube.

Table 5.—Nagaoka-Honda Effect [12]

B, B_0 = Magnetic induction in specimen in field H when pressure = P, pressure = 0; $A = (B - B_0)/BP$. Unit of A = 10^{-5} cm²/kg = 1.0197×10^{-11} barye^{-1} = 7.0307×10^{-7} in.²/lb. = $1.0332 \times 10^{-5} A_n^{-1}$; of H = 1 cgsm = 1 gauss; of P = 1 kg/cm² = 980 665 barye = 14.22 lb./in.² = $0.9678 A_n$.

Fe, C, Iron;* H = 1.30				Fe, Iron;† P = 7 510			
P	A	P	A	H	A	H	A
1 010	−2.13	7 590	−1.90	0.27	−2.27	1.35	−5.38
1 930	−2.10	8 490	−1.95	0.38	−3.31	1.62	−4.72
3 470	−2.01	9 570	−1.94	0.54	−3.67	1.89	−3.86
4 370	−1.91	10 320	−1.95	0.76	−4.45	2.16	−3.14
5 360	−1.94	11 290	−1.94	0.97	−5.15	2.70	−2.27
6 460	−1.94			1.08	−5.51	3.79‡	−1.43

* Carbonized.
† Pure iron.
‡ For H = 4.87, A = −0.99.

Table 6.—Demagnetization of Rods by Impact and by Torsion

$\phi[\phi']$ = total magnetic flux across given section of rod before [after] impact or torsion; x = distance of section from end struck, or from clamped end; θ = twist per unit length; $D = (\phi - \phi')/\phi$. Unit of ϕ = 1 cgsm = 1 maxwell; x = 1 cm; θ = 1′ per cm; D = 1%.

Tool steel [5]; single impact at x = 0; total length = 110 cm

x	φ	D	x	φ	D	x	φ	D
2	1296	11.0	29	7266	12.4	89	6301	10.6
5	2572	12.9	35	7831	12.0	95	5282	10.5
8	3349	14.2	44	8355	11.6	98	4666	10.5
11	4159	14.1	56	8559	11.5	101	3960	10.4
14	4864	13.9	68	8260	11.3	104	3122	10.2
17	5484	13.6	77	7675	10.9	107	2189	9.6
23	6497	13.0	83	7082	10.7	110	1089	8.2

Norway iron [5]; uniform torsion; total length 110 cm. For $30 < x < 80$, D is independent of x, and = D_c; for points nearer the ends, D may differ from D_c by 12% of D_c. Value of ϕ at central section = 1500 maxwell.

θ	0.818	1.96	2.84	4.42	6.16
D_c	21.6	43.2	55.7	68.2	77.6

LITERATURE

(For a key to the periodicals see end of volume)

[1] Bachmetjew, *8*, **43**: 723; 91. [2] Barkhausen, *68*, **20**: 401; 19. [3] Barrett, *3*, **47**: 51; 74. [4] Barrett, *58*, **26**: 585; 82. [5] Becknell, *2*, **8**: 504; 16. [6] Beetz, *8*, **128**: 193; 66. [7] Bidwell, *5*, **55**: 228; 94. **56**: 94; 94. [8] Brackett, *2*, **5**: 257; 97. [9] Brown, *117*, **15**: 121; 16.

[10] Bucherer, *8*, **58**: 564; 96. [11] Cantone, *22*, **6**: 252; 90. [12] Chi-Sun Yeh, *0*; work with P. W. Bridgman, Harvard Univ. [13] Dorsey, *2*, **30**: 698; 10. [14] Elias, *64V*, **23**: 455; 14. [15] Ewing, *Magnetic induction in iron and other metals*. New York, Van Nostrand, 1900. [16] Groesser, *Diss.*, Rostock. [17] Guillemin, *34*, **22**: 264, 432; 46. [18] Guthe and Austin, *31A*, **2**: 297; 06. [19] Heaps, *3*, **22**: 900; 11. **24**: 813; 12.

[20] Heaps, *2*, **24**: 60; 24. [21] Honda and Kido, *159*, **9**: 221; 20. [22] Honda and Shimizu, *3*, **4**: 645; 02. [23] Honda and Shimizu, *3*, **5**: 650; 03. [24] Honda and Shimizu, *44*, **19**: No. 10; 03. [25] Honda and Terada, *3*, **13**: 36; 07. [26] Honda and Terada, *3*, **14**: 65; 07. [27] Joule, *3*, **30**: 76, 225; 47. [28] Kirstein, *63*, **4**: 829; 03. [29] Knott, *174*, **32**: 193; 87. *3*, **30**: 244; 90. **37**: 141; 94.

[30] Knott, *174*, **38**: 527; 97. [31] Laws, *3*, **19**: 685; 10. [32] Matteucci, *6*, **53**: 385; 58. [33] Maurain, *34*, **121**: 248; 95. [34] Miller, *2*, **25**: 250; 25. [35] More, *3*, **40**: 345; 95. [36] Nagaoka, *3*, **37**: 131; 94. [37] Nagaoka and Honda, *in* Honda and Shimizu, *44*, **13**: 263; 00. [38] Nagaoka and Honda, *3*, **46**: 261; 98. [39] Nagaoka and Honda, *3*, **4**: 45; 02.

[40] Onnes and Beckman, *64P*, **15**: 319; 12. [41] Paillot, *34*, **132**: 1318; 01. [42] Patterson, *3*, **3**: 643; 02. [43] Pidgeon, *2*, **13**: 209; 19. [44] Rowland and Bell, *3*, **26**: 105; 88. [45] Smith, *2*, **19**: 285; 22. [46] Stevens, *2*, **7**: 19; 98. [47] Stevens, *2*, **10**: 161; 00. [48] Stevens, *2*, **11**: 95; 00. [49] Stevens and Dorsey, *2*, **9**: 116; 99.

[50] Strouhal and Barus, *8*, **14**: 54; 81. [51] Thomson, *Collected papers in physics and engineering*, **2**: 286; 12. [52] Tomlinson, *3*, **29**: 394; 90. [53] Tyndall, *2*, **24**: 439; 24. [54] Villari, *8*, **126**: 87; 66. [55] Wertheim, *34*, **22**: 336; 46. [56] Wiedemann, *Die Lehre von der Elektricität*, III. Braunschweig, Vieweg, 1893–98. [57] Williams, *3*, **9**: 77; 05. [58] Williams, *2*, **32**: 281; 11. [59] Williams, *2*, **4**: 498; 14.

[60] Williams, *66*, **19**: 130; 19. [61] Williams, *2*, **22**: 526; 23. [62] Williams, *Testing*, **1**: 190; 24. [63] Zschiesche, *96*, **11**: 201; 22.

ATMOSPHERIC ELECTRICITY

W. F. G. Swann

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Potential Gradient.—*See* Tables 1, 2 and Figs. 1, 2, 3, 4. The values are supposed to represent the gradient as it would be if the effective surface of the earth were a true plane. The main sources of error lie in (*a*) an uncertainty of the correction for the non-planar form of the effective surface of the earth, and (*b*) errors due to leakage from the collector system (4). No precise limits of accuracy can be given without a precise study of each individual case, which is impracticable. As a result of the first (*a*) source of error, determinations on land have occasionally been unexpectedly found in error by as much as 50%. The importance of the second (*b*) source of error depends upon the speed of the collector; in a typical case in which it required one minute to obtain a reading within 1% of its final value, the error due to leakage resulting from atmospheric conductivity alone amounted to 1%.

From an analysis of the diurnal variation over the ocean, Mauchly (22) has concluded that this variation is primarily due to a 24 hour wave which progresses according to universal, rather than local, time; he finds the same 24 hour wave from land observations, but for these it is not so large a part of the entire effect.

Table 1.—Potential Gradient: Land Values

For ocean values, *see* Table 2. Mean values over the interval indicated: Long. = longitude east of Greenwich, Pot. Grad. = potential gradient, potential increasing upwards. (*See also* Figs. 1 to 4.) Unit of Pot. Grad. = 1 volt/meter = $3.33_6 \times 10^{-5}$ cgse unit per cm.

Place	Lat.	Long.	Interval	Pot. Grad.	Lit.
Karasjok	69.3° N.	25.6°	1 yr	139	(6)
Upsala	59.9 N.	15.2	2	70	(24)
Moscow	55.7 N.	37.6		112	(18)
Potsdam	52.4 N.	13.1	4	245	(6)
Kew	51.5 N.	359.7	15	304	(6)
Seeham	48.0 N.	13.1	12	84	(29)
Kremsmünster	48.0 N.	14.1	10	107	(6)
Munich	48.1 N.	11.6	5	168	(6)
Davos	46.8 N.	9.8	2	64	(6)
Trieste	45.6 N.	13.8	2	73	(6)
Perpignan	42.7 N.	357.1	2	55	(30)
Tortosa	40.8 N.	0.5	7	114	(6)
Buenos Aires	34.6 S.	301.6	1	126	(3)
Petermann I.	65.2 S.	295.8	1	176	(14)

Table 2.—Potential Gradient, Ionic Content and Conductivity of the Atmosphere, and Air-Earth Current Density: Ocean Values

For land values, *see* Table 1, potential gradient; Table 3, ionic content; Table 4, conductivity and current density. Compiled from (4, 4.1); data are averages for the region, and are based on observations distributed over one or two weeks and taken near 10 A. M. local mean time. Long. = longitude east of Greenwich; Pot. Grad. = potential gradient, potential increasing upwards; n_+ [n_-] = number of + [−] ions per cm³ of air; $\lambda_+[\lambda_-]$ = conductivity due to + [−] ions; i = current density of positive current from air to earth, $i = (\lambda_+ + \lambda_-) \times$ potential gradient. Dates are written thus: 3:20:15 = March 20, 1915. Unit of Pot. Grad. = 1 volt/meter = $3.33_6 \times 10^{-5}$ cgse unit (per cm); of λ_+ and λ_- = 10^{-4} cgse unit; of i = 10^{-7} cgse unit (per cm³).

Region		Mean date	Pot. Grad.*	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	$\lambda_+ + \lambda_-$	$\frac{\lambda_+}{\lambda_-}$	i
Lat.	Long.							
°N.	°E.							
12–31	283–293	12:18:15	117	490	1.03	1.70	1.18	5.8
2– 8	260–280	4:21:15	126	760	1.20	2.75	1.18	11.1
8–16	233–258	5: 5:15	115	860	1.05	2.90	1.24	10.4
17–21	204–230	5:16:15	109	920	0.93	3.28	1.05	12.1
22–36	199–201	4: 7:15	112	690	1.16	2.57	1.45	9.3
37–52	190–196	4:15:15	129	730	1.27	2.54	1.13	10.4
56–59	175–193	8:11:15	155	790	1.26	2.62	1.15	12.4
32–54	163–173	8:24:15	144	610	1.41	2.35	1.33	10.9
14–30	165–171	9: 8:15	115	880	1.16	3.19	1.22	12.0
2–14	162–166	9:23:15	102	820	1.19	3.18	1.18	10.7
1–19	158–163	10: 8:15	115	670	1.19	2.66	1.13	10.3
22–47	155–173	10:24:15	104	850	1.19	2.76	1.14	9.5
°S.	°E.							
46–56	175–198	12:11:15	109	840	1.28	2.63	1.25	10.0
59–60	209–271	12:24:15	145	660	1.30	2.50	1.34	11.7
54–59	280–327	1: 8:16	165	690	1.25	2.54	1.25	12.2
52–54	349–42†	1:26:16	114	630	1.15	2.10	1.23	7.9
36–52	47–93	2: 8:16	110	810	1.15	2.71	1.22	9.8
34–54	95–108	2:22:16	118	750	1.18	2.89	1.19	10.9
41–59	110–133	3: 8:16	138	820	1.26	3.02	1.25	14.2
45–57	135–173	3:26:16	122	870	1.18	2.83	1.14	14.1

* Deduced from observed change in potential of a conductor that is moved in the earth's field (4).

† Taken, of course, over the lesser portion of the small circle.

Ionic Content.—The numbers n_+ and n_-, of positive and of negative ions per cm³, are derived from $(n_+ + n_-)/2$ and n_+/n_- (Table 3). As the atmospheric potential gradient tends to decrease the rate at which negative ions enter the measuring instrument, the values of n_- are apt to be too low. The size of this error depends upon instrumental details and the effect of surrounding objects, and may exceed 20% (21, 23, 37, 38, 39). With the Ebert aspiration apparatus, the ions measured are mostly the so-called "small" ions, which, in laboratory experiments, have mobilities of 1.3 cm/sec per volt/cm for the +ions and 1.8

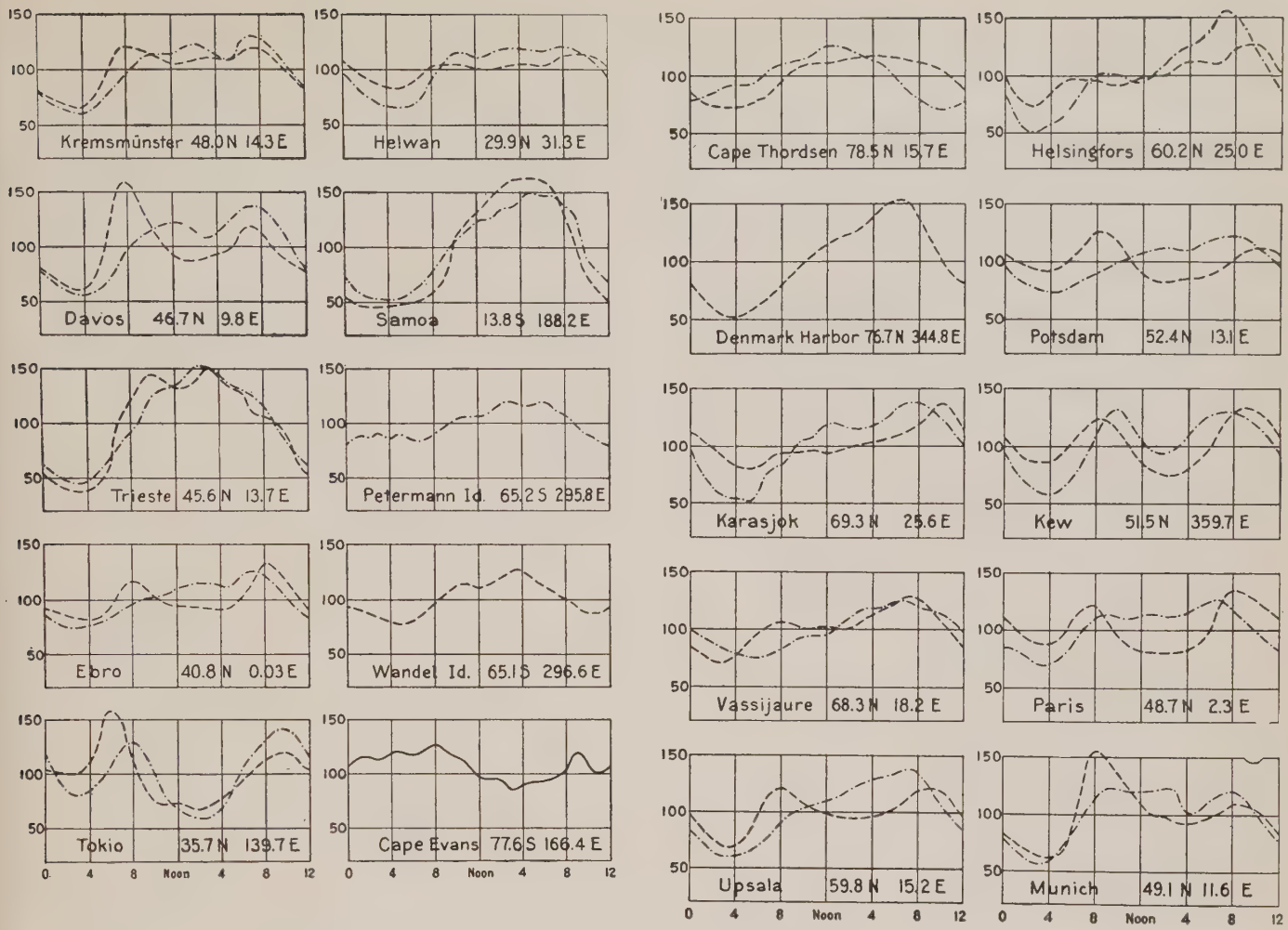
Kremsmünster 48.0 N 14.3 E
Helwan 29.9 N 31.3 E
Cape Thordsen 78.5 N 15.7 E
Helsingfors 60.2 N 25.0 E
Davos 46.7 N 9.8 E
Samoa 13.8 S 188.2 E
Denmark Harbor 76.7 N 344.8 E
Potsdam 52.4 N 13.1 E
Trieste 45.6 N 13.7 E
Petermann Id. 65.2 S 295.8 E
Karasjok 69.3 N 25.6 E
Kew 51.5 N 359.7 E
Ebro 40.8 N 0.03 E
Wandel Id. 65.1 S 296.6 E
Vassijaure 68.3 N 18.2 E
Paris 48.7 N 2.3 E
Tokio 35.7 N 139.7 E
Cape Evans 77.6 S 166.4 E
Upsala 59.8 N 15.2 E
Munich 49.1 N 11.6 E
150
100
50
0 4 8 Noon 4 8 12

FIG. 1.—Diurnal variation of potential gradient (24).

Ordinates = percentage of the mean gradient for the season (summer, winter, or year), abscissae = local mean time. Summer – – – winter –. –, year — .

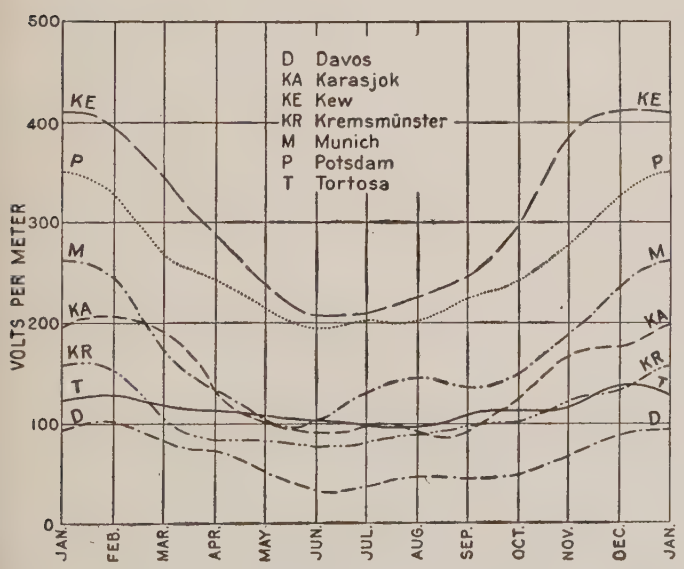

FIG. 2.—Annual variation of potential gradient: Northern hemisphere (6).

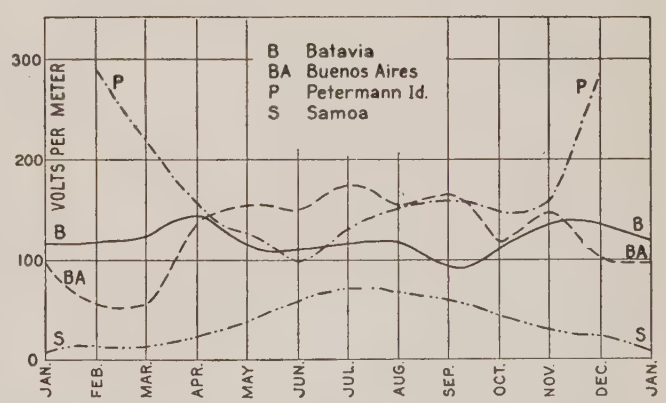

FIG. 3.—Annual variation of potential gradient: Southern hemisphere (6).

for the −ions. In addition to these, so-called "large" ions of mobility about 1/3000 cm/sec per volt/cm, and "intermediate" ions of mobility of the order 0.01 are to be found in the atmosphere. The numbers of these larger ions vary very widely. Representative ratios of large to small ions are: In Paris 50 (Langevin), in Swiss Alps and in Freiburg 2 to 3 (Gockel), in Dublin 200 (McClelland and Kennedy).

As determined on the fourth cruise of the Carnegie, the mobilities of the small ions over the Pacific and the sub-Antarctic Oceans averaged 1.3 cm/sec per volt/sec for both + and − ions. The large abnormalities in the mobilities of atmospheric "small" ions reported by some observers are probably attributable largely to experimental errors inherent in the methods used, the customary method with the Ebert apparatus leading in a large percentage of cases of observatory data to even a negative value of the mobility.

TABLE 3.—IONIC CONTENT OF ATMOSPHERE: LAND VALUES

For ocean values, *see* Table 2. These values have been reduced on the assumption that $e = 4.8 \times 10^{-10}$ es unit; most of them were obtained with Ebert's aspiration apparatus (18, 36). Values of n_+/n_- are apt to be too high, and of n_- too low. Dates are written thus: *8*: 19, 20; **05** = August 19, 20, 1905. Long. = longitude east of Greenwich. Unit of n_+ and n_- = 1 ion per cm.[3]

Place	Lat.	Long.	Period	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	Lit.
Karasjok	69.3° N.	25.6	1 yr	750	1.17	(31)
Kew	51.5 N.	359.7	**11** to **14**	330	1.40	(45)
Freiburg	50.9 N.	16.3	**04** to **05**	624	1.36	(12)
Munich	48.1 N.	11.6	*8*: 19, 20; **05**	994	1.24	(10)
Aibling	47.9 N.	12.0	**06**, summer	950	1.25	(8)
Aibling	47.9 N.	12.0	**06**, winter	913	1.19	(8)
Jachenau	47.6 N.	11.4	*8*: **05**	915	2.16	(10)
Barcelona*	41.4 N.	2.2	1 day	541	1.30	(10)
Seewalchen	N.		*8*: 6 to *9*: 20; **04**	862	1.18	(27)
Bolivia†	S.		*5*: to *9*: **09**	1980	1.08	(19)
Buenos Aires	34.6 S.	301.6	*5*: **11** to *4*: **12**	1980	1.04	(3)

* Barcelona harbor.

† In high Cordilleras.

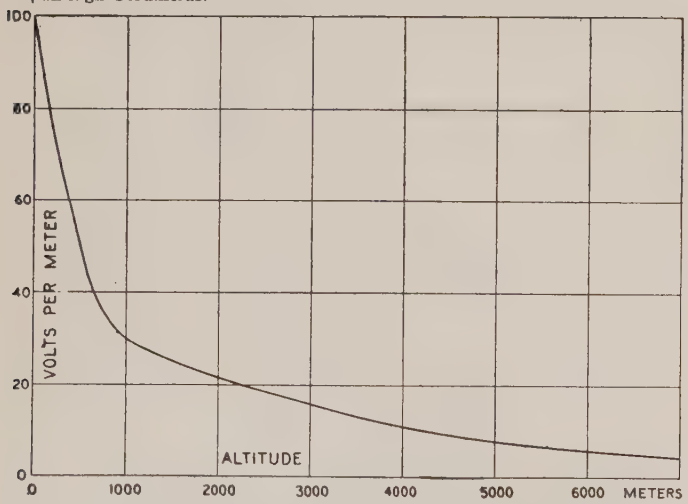

FIG. 4.—Variation of potential gradient with altitude (30).

Mean of results of various observers, each set reduced to correspond to 25 volt per meter at an altitude of 1500 meter.

Conductivity of Atmosphere.—(Tables 2 and 4.) The conductivity $(\lambda_+ + \lambda_-)$ of the atmosphere is the sum of the conductivities due to the presence of the + and of the − ions. For methods, *see* (18). Values of $(\lambda_+ + \lambda_-)$ obtained by the Gerdien apparatus are apt to be too low, owing to neglect of effect of rod supporting the central cylinder. This error may amount to 10% or 15% (35). In the ocean data recorded in Table 2, the measurements were taken in such a manner as to avoid this error. For land observations, the measured value of λ_+ is apt to be too high on account of the collection on the apparatus of radioactive material from the atmosphere. This error may amount to 5%.

Values obtained by Schering's method, which involves measurement of rate of flow of charge from a body (usually a long wire) exposed to the free air, are apt to be too low on account of effect of earth's electric field (34), unless that field near the apparatus is very small, as seems to be the case at Potsdam. When this effect is neglected the values obtained are 20% to 30% lower than those obtained with the Gerdien apparatus.

TABLE 4.—CONDUCTIVITY OF ATMOSPHERE, AND AIR-EARTH CURRENT DENSITY: LAND VALUES

For ocean values, *see* Table 2; for values at high altitude, *see* Table 5. Long. = longitude east of Greenwich; λ_+, λ_- = conductivity due to +ions, −ions; i = current density of positive current from air to earth, $i = (\lambda_+ + \lambda_-) \times$ potential gradient. Dates are written thus: *5*: **09**–*4*: **10** = May, 1909 to April, 1910; *4*: 1–17; **06** = April 1 to 17, 1906. Unit of λ_+ and $\lambda_- = 10^{-4}$ cgse unit; of $i = 10^{-7}$ cgse unit.

Place	Lat.	Long.	Period	$\lambda_+ + \lambda_-$	λ_+/λ_-	i	Lit.
Greenland*	73.0° N.		**07** to **08**	5.53	1.28	12.6	(6)‡
Edinburgh†	56.0 N.	356.9	*5–6*: **09**	0.72		8.4	(5)
Peebles†	55.7 N.	356.8	*9*: **06**–*10*: **07**	2.16		13.4	(42)
Potsdam§	52.4 N.	13.1	*5*: **09**–*4*: **10**	0.95	1.16	7.1	(17)
Göttingen*	51.5 N.	9.9	*4*: 1–17; **06**	2.22	0.98	8	(11)
Munich†	48.1 N.	11.6	*1–12*: **09**	0.98		6.1	(46)
Seeham§	48.0 N.	346.9	**08–20**	2.64	1.02	6.9	(29)
Davos§	46.8 N.	9.8	1 year	2.68	1.13	5.2	(9)
Simla†	31.2 N.	77.8	*11*: **09**	11.6		10.8	(33)
Samoa*	13.8 S.	188.2	*6*: **07**–*3*: **08**	4.5	1.04	7.0	(1)
Buenos Aires*	34.6 S.	301.6	*4, 6*: **12**	1.32	1.02	5.7	(3)
Petermann I*	65.2 S.	295.8	9 months	4.16	1.62	22.6	(6)‡

* By Gerdien's conductivity apparatus; values may be too low by 10 % or 15 %, *see* text.

† By C. T. R. Wilson's method. Values of $(\lambda_+ + \lambda_-) = 2\lambda_0$, λ_0 = directly observed λ; $i = 2\lambda_0 \times$ potential gradient.

‡ Vol. III, p. 123 (6); observed by Wegener.

§ By Schering's method; values may be too low, *see* text.

TABLE 5.—CONDUCTIVITY OF ATMOSPHERE AT HIGH ALTITUDES (41)

Results of 4 ascensions; in each, data are reduced to correspond with $(\lambda_+ + \lambda_-) = (1 \text{ to } 1.5) \times 10^{-4}$ cgse unit at earth's surface. Altitude = maximum altitude, tabulated values of $(\lambda_+ + \lambda_-)$ correspond to that altitude.

Ascension	1	2	3	4	Unit
$(\lambda_+ + \lambda_-)$	16.5	18.8	23.2	37.3	10^{-4} cgse
Altitude	5300	5385	8345	8865	meter

Miscellaneous Data.—The *air-earth current density* is computed from the potential gradient and the conductivity, and is usually expressed in cgs electrostatic units per cm² (=cgse units). *See* Tables 2 and 4.

Rate of Recombination of Atmospheric Ions.—As determined by laboratory experiments with artificial ionization, the coefficient α in $-\frac{dn_\pm}{dt} = \alpha n_+ n_-$ has a value about 1.6×10^{-6} cm³ per (ion sec) (*cf.* p. 110), but for atmospheric ions, α has, in general, been found to be of the order of (2 or 3) $\times 10^{-6}$. Recent work (25, 28) indicates that for atmospheric ions $-\frac{dn_\pm}{dt} = \alpha n_+ n_- + \beta n_\pm$, where β is considerably more important than α.

Charge on Rain.—Rain may be charged either + or −. In Simla, Simpson (32) found that + precipitation occurred 2.5 times as frequently as − precipitation, and in a long series of observations the total + charge brought down was 3.2 times as great as the total − charge. The corresponding values found at Potsdam (26) by Schindelhauer (confirmed by Kähler) are 2.2 and 1.4, and at Le-Puy-en-Velay by Baldit (2) are 2.86 and 1.36,

respectively. The charge on rain is generally less than 1 es unit per cm.[3]

Lightning.—Humphreys (16) estimates that the current associated with a lightning flash may, in certain cases, be of the order of 90 000 amperes. From a comprehensive series of experiments, C. T. R. Wilson (43) concludes that the average charge brought down in a lightning flash is of the order of 20 coulombs, and that the potential differences involved in the discharge are of the order of 10^9 volt.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *536*, **9**, No. 2; 11. *507*, **28**: 430; 11. (2) Baldit, *Soc. météorol. France, Ann.*, **59**: 105; 11. *199*, **9**: 92; 12. (3) Berndt, *Veröff. deut Wiss. Ver. Buenos Aires*, No. **3**. Berlin, 1913. *507*, **30**: 363; 13. (4) Bauer, Peters, Fleming, Ault and Swann, *152*, No. **175, III**; 17. (4-1) Ault and Mauchly, *152*, No. **175, V**; 26. (5) Carse and MacOwan, *68*, **30**: 460; 10. (6) Chauveau, *Électricité atmosphérique*. Paris, Douin, 1922–1925. 3v. (7) Chree, *Encyclo. Brit.*, 11th ed., **2**: 860; 10. 13th ed., **1**: 257; 26. (8) Daunderer, *63*, **10**: 113; 09. (9) Dorno, *Studie über Licht und Luft der Hochgebirges*. Braunschweig, Vieweg, 1911.

(10) Ebert, *63*, **6**: 641; 05. (11) Gerdien, *188*, **1907**: 77. (12) Gockel, *507*, **23**: 53, 339; 06. **25**: 9; 08. (13) Gockel, *Die Luftelektrizität*. Leipzig, Hirzel, 1908. (14) von Hann, *507*, **31**: 504; 14. (15) Hess, *Die elektrische Leitfähigkeit der Atmosphäre und ihre Ursachen*. Braunschweig, Vieweg, 1926. (16) Humphreys, *Physics of the air*. Philadelphia, Lippincott, 1920. (17) Kähler, *Veröff. kgl. preuss. meteorol. Inst.*, No. **223**; 10. (18) Kähler, *Luftelektrizität*. 2nd ed. Gruyter, 1921. (19) Knoche, *63*, **12**: 179; 11.

(20) Mache and von Schweidler, *Die atmosphärische Elektrizität*. Braunschweig, Vieweg, 1909. (21) Mackell, *2*, **21**: 436; 23. (22) Mauchly, *268*, **28**: 61; 23. (23) Nichols, *268*, **21**: 87; 16. (24) Norinder, *468*, **58**: No. 4; 18. (25) Power, *143*, **196**: 327; 23. (26) Schindelhauer, *Abhandl. kgl. preuss. meteorol. Inst.*, No. **213**; 09. No. **263**; 13. Kähler, *63*, **9**: 258; 08. (27) von Schweidler, *75*, **113, IIA**: 1433; 04. (28) von Schweidler, *75*, **127, IIA**: 953; 18. **128 IIA**: 947; 19. (29) von Schweidler, *200*, **18**: 1; 22.

(30) von Schweidler and Kohlrausch, *B90*, Vol. 3. (31) Simpson, *62*, **205**: 61; 06. (32) Simpson, *62*, **209**: 379; 09. *5*, **83**: 394; 10. (33) Simpson, *3*, **19**: 715; 10. (34) Swann, *268*, **19**: 23; 14. (35) Swann, *268*, **19**: 81; 14. (36) Swann, *268*, **19**: 171; 14. (37) Swann, *268*, **19**: 205; 14. (38) Swann, *268*, **21**: 99; 16. (39) Swann, *2*, **21**: 449; 23.

(40) Swann, *Encycl. Brit.*, 1927. (41) Wigand, *268*, **19**: 93; 14. *199*, **11**: 204; 19. (42) Wilson, *5*, **80**: 537; 08. (43) Wilson, *62*, **221**: 73; 21. (44) Wilson, *B2*, Vol. 2. (45) *Observatories Year Book*, **1926**: 330. (46) Lutz, *213*, **1911**: 305.

TERRESTRIAL MAGNETISM

W. F. G. Swann

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General Conclusions.—The magnetic field of the earth is roughly that of a uniformly magnetized sphere; at external points the field of such a sphere is equivalent to that due to a magnetic doublet placed at the center of the sphere. The axis of the doublet is inclined to the axis of rotation. If M is its moment, and M_p and M_e are, respectively, the axial and the equatorial components of M, then, according to an analysis by L. A. Bauer (4), $M = 8.04(10)^{25}$, $M_p = 7.88(10)^{25}$, $M_e = 1.60(10)^{25}$ cgs magnetic unit; the axis of the doublet intercepts the northern hemisphere at latitude 78° 32′ N. and longitude 69° 08′ W.; and the average intensity of magnetization of the earth is 0.074 cgs magnetic unit.

The magnetic poles, defined as the places where the field is vertical, are not where the prolonged axis of the doublet intersects the earth's surface. From observations between 1903 and 1906, Amundsen placed the north magnetic pole at lat. 71° N, long. 96° W.; from data obtained on the "Discovery," 1902 to 1904, the probable position of the south magnetic pole is latitude 72° 50′ S., longitude 156° 20′ E.

From a harmonic analysis of the field, Gauss concluded that part of it is of external origin. Analyses by Schmidt (13) and by Bauer (4) lead these authors to conclude that a part of the field is not derivable from a potential; Bauer (4) concludes that about 3% of the field is of non-potential origin, and, of the remainder, 94% arises from internal, and 3% from external, causes. The non-potential portion would correspond, on classical electromagnetic theory, to vertical currents (*see* Table 1).

TABLE 1.—VERTICAL CURRENT DENSITIES AS COMPUTED FROM MAGNETIC DATA

Computed by Bauer [3] from magnetic data of 1920. The average value, regardless of sign, is about 10 000 times the atmospheric-electric current density, *see* p. 442. Dyson and Furner [8] conclude that such vertical currents are not indicated with any certainty, although there is some evidence for them. A + sign indicates an upward positive current; i_N [i_S] = current density in northern [southern] hemisphere. Unit of i_N and $i_S = 10^{-3}$ ampere/km^2 = 3.0×10^{-4} cgse (per cm^2).

Lat.	i_N	i_S
90° to 50°	+21	+18
50 to 45	+45	+34
45 to 40	− 6	−47
40 to 35	+18	−22
35 to 30	+ 8	−31
30 to 25	−29	+19
25 to 20	−37	+58
20 to 15	−19	+41
15 to 10	−33	−41
10 to 5	−53	+14
5 to 0	−18	+ 9

TABLE 2.—MAGNETIC ELEMENTS AT VARIOUS OBSERVATORIES: RECENT DATA [9]

D = declination (east or *west*); *I* = inclination or dip (north or *south*); *H* = horizontal intensity, *Z* = vertical intensity. *Italics* indicate that the quantity is to the south (latitude and *I*) or the west (longitude and *D*); in column "Yr," 24 indicates 1924; Long. = longitude east or *west* from Greenwich. Unit of *H* and $Z = 1\gamma = 10^{-5}$ gauss = 10^{-5} cgsm.

Observatory	Lat.	Long.	Yr	*D*	*I*	*H*	*Z*
Matochkin Shar	73° 15′	56° 24′	24	20° 35′	80° 03′	9 520	54 270
Sodankylä	67 22	26 39	22	1 22.6	75 40.5	12 561	49 187
Pavlovsk	59 41	30 29	24	3 16.1	71 07.9	15 818	46 970
Sitka	57 03	*135 20*	22	30 29.1	74 22.4	15 560	55 631
Ekaterinburg	56 50	60 38	24	11 00.8	71 58.4	16 578	50 942
Rude Skov	55 51	12 27	21	*7 45.2*	69 01.2	17 105	44 607
Kasan	55 50	48 51	24	8 53.5	70 07.6	17 310	47 517
Eskdalemuir	55 19	*3 12*	20	*16 49.7*	69 39.5	16 706	45 062
Meanook	54 37	*113 20*	24	27 17.7	77 73.7	12 866	59 984
Stonyhurst	53 51	*2 28*	24	*15 05.3*	68 41.7	17 276	44 281
Wilhelmshaven	53 32	8 09	11	*11 28.2*	67 30.7	18 110	43 747
Potsdam	52 23	13 04	23	*6 56.9*	66 36.5	18 565	42 920
Seddin	52 17	13 01	22	*7 09.4*	66 32.8	18 614	42 905
Irkutsk (Zuja)	52 28	104 02	20	1 02.3	71 06.6	19 277	56 337
De Bilt	52 06	5 11	24	*10 38.3*	66 52.7	18 372	43 024
Valencia	51 56	*10 15*	20	*19 17.9*	68 05.3	17 840	44 353
Bochum	51 29	7 14	21	*10 10.4*			
Kew	51 28	*0 19*	20	*14 31.0*	66 57.9	18 410	43 297
Greenwich	51 28	0 00	23	*13 35.1*	66 51.9	18 431	43 137
Uccle	50 48	4 21	16	*12 28.4*	66 02.8	18 971	42 703
Hermsdorf	50 46	16 14	13	*6 58.2*			
Prague	50 05	14 25	21	*6 24.2*			
Val Joyeux	48 49	2 01	22	*12 31.5*	64 39.6	19 661	41 517
Munich	48 09	11 37	13	*9 06.2*	63 04.6	20 623	40 609
			21	*7 53.6*			
O'Gyalla	47 53	18 12	18	*5 21.9*		20 917	
Odessa	46 26	30 46	10	*3 35.9*	62 26.9	21 707	41 606
Pola	44 52	13 51	22	*6 28.0*	60 12.8	22 090	38 591
Agincourt	43 47	*79 16*	24	*7 05.8*	74 44.4	15 752	57 733
Tiflis	41 43	44 48	13	3 09.1	56 51.1	25 217	37 612
Capodimonte	40 52	14 15	14			24 166	
Ebro (Tortosa)	40 49	0 31	24	*11 20.2*	57 30.5	23 359	36 678
Coimbra	40 12	*8 25*	20	*15 21.5*	58 22.8	23 087	37 496
Cheltenham	38 44	*76 50*	22	*6 27.7*	70 57.6	19 020	55 115
Athens	37 59	23 42	08	*4 53.0*	52 11.7	26 197	33 613
San Miguel	37 46	*25 39*	20	*19 24.9*	60 26.0	23 123	40 759
San Fernando	36 28	*6 12*	24	*13 23.5*	53 46.8	25 016	
Kakioka	36 14	140 11	16	*5 17.6*	49 31.7	29 743	34 859
Tsingtau	36 04	120 19	20	*4 12.9*	52 07.0	30 817	39 610
Tucson	32 15	*110 50*	22	13 47.5	59 29.0	26 839	45 533
Lukiapang	31 19	121 02	20	*3 21.4*	45 30.7	33 175	33 773
Dehra Dun	30 19	78 03	22	1 43.2	45 02.6	32 927	33 091
Helwan	29 52	31 20	19	*1 30.6*	41 09.6	29 947	26 175
Hongkong	22 18	114 10	24	*0 23.8*	30 42.8	37 294	22 155
Honolulu	21 19	*158 04*	22	9 57.1	39 24.5	28 794	23 658
Teoloyucan	19 45	*99 11*	22	9 09.9			
Toungoo	18 56	96 27	22	*0 29.7*	23 07.2	39 156	16 717
Alibag	18 38	72 52	22	0 12.6	25 05.0	36 967	17 303
Vieques	18 09	*65 27*	22	*4 00.9*	51 33.1	27 695	34 880
Antipolo	14 36	121 10	20	0 35.9	16 11.7	38 100	11 065
Kodaikanal	10 14	77 28	22	*1 58.7*	4 40.1	37 878	3 093
Batavia-Buitenzorg	*6 11*	106 49	24	0 52.9	*32 04.3*	36 821	23 072
St. Paul de Loanda	*8 48*	13 13	19	*14 49.0*			
Huancayo	*12 03*	*75 20*	24	8 01.7	0 54.6	29 755	395
Apia	*13 48*	*171 46*	24	10 19.2	*30 07.5*	35 249	20 453
Tananarive	*18 55*	47 32	14	*8 25.2*	*53 37.9*	22 484	30 532
Mauritius	*20 06*	57 33	23	*10 49.2*	*52 33.7*	22 982	30 018
Vassouras	*22 24*	*43 39*	23	*11 42.8*	*15 53.7*	24 407	6 950
Watheroo	*30 19*	115 53	24	*4 18.3*	*64 05.2*	24 750	50 941
Pilar	*31 40*	*63 53*	20	7 48.6	*25 41.2*	25 297	12 168
Toolangi	*37 32*	145 28	20	8 00.8	*67 55.1*	22 874	56 384
Christchurch	*43 32*	172 37	23	17 11.7	*68 12.0*	22 209	55 526
Orcadas	*60 43*	*44 47*	12	4 46.5	*54 26.0*	25 343	35 442

TABLE 3.—MAGNETIC ELEMENTS FOR EACH 10° OF LATITUDE AND LONGITUDE

Data obtained from charts [5] compiled at Royal Observatory, Greenwich, England, 1922. A ? indicates that the curves were too widely spaced to permit satisfactory interpolation. *D* = declination (east or *west*); *I* = inclination or dip (north-seeking pole down or *up*); *H* = horizontal intensity; *italics* indicate that *D* is to the west or that *I* is such that north-seeking pole is up. Unit of $H = 100\gamma = 10^{-3}$ gauss = 10^{-3} cgsm.

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N		
Long.	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*
0° E.	?	*18.7°*	?	153	*16.3°*	72°	193	*13.5°*	65°	240	*11.8°*	57°	280	*11.0°*	43°	308	*11.1°*	26°	318	*12.6°*	5°
10 E.	?	*10.6*	?	157	*9.7*	71	197	*9.0*	64	244	*8.2*	55	286	*7.9*	42	316	*7.9*	23	325	*8.7*	2
20 E.	120	*3.3*	?	160	*3.4*	71	203	*3.7*	64	248	*4.2*	54	292	*4.5*	42	322	*5.0*	23	331	*6.2*	1
30 E.	120	2.6	?	163	2.1	71	208	1.0	64	253	*0.9*	54	299	*1.6*	41	330	*2.4*	22	337	*3.7*	2
40 E.	?	7.8	?	162	6.2	71	211	4.8	64	258	2.8	54	306	1.3	41	339	0.1	22	344	*1.3*	2
50 E.	?	13.0	?	160	10.0	71	212	7.2	65	265	4.8	55	313	3.2	42	344	1.8	23	352	0.8	3
60 E.	106	18.2	?	156	12.8	72	212	8.3	65	271	5.6	56	318	3.5	42	352	1.7	25	361	0.1	5
70 E.	98	?	?	150	14.1	73	212	8.8	66	275	5.7	56	324	2.8	43	361	0.4	26	372	*1.9*	5
80 E.	88	?	?	148	13.8	73	210	8.0	67	279	4.7	57	333	1.8	43	373	*0.6*	26	382	*2.5*	4
90 E.	80	?	80	137	10.7	74	210	6.2	67	282	?	57	342	?	43	383	*0.5*	26	395	*1.5*	4
100 E.	?	16.0	80	135	6.8	75	212	2.7	68	283	?	57	346	?	43	389	?	25	?	0.0	3
110 E.	?	10.0	80	137	0.4	75	216	*1.3*	68	284	*1.8*	57	344	*1.4*	43	384	?	25	?	1.2	3
120 E.	?	3.9	80	144	*5.9*	75	224	*6.1*	67	285	*5.0*	56	338	*2.9*	43	373	*0.4*	25	389	1.4	4

TABLE 3.—(*Continued*)

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N.		
Long.	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*
130 E.	83	*1.0*	80	157	?	74	232	*9.4*	66	285	*6.8*	55	326	*3.8*	42	360	*0.9*	26	379	1.5	5
140 E.	92	*4.8*	80	167	?	73	234	*9.4*	64	281	*6.6*	53	313	*3.6*	41	343	*0.5*	26	364	2.2	6
150 E.	100	0.0	?	174	*8.0*	72	235	*6.7*	62	274	*4.2*	52	300	*1.6*	41	325	1.0	26	348	3.7	7
160 E.	109	4.3	?	179	*2.3*	71	234	*2.2*	61	267	*0.4*	52	291	1.6	41	313	3.9	27	338	5.7	9
170 E.	114	10.2	?	182	2.6	70	230	2.6	61	261	3.9	52	283	5.5	42	304	6.8	29	330	8.0	12
180 E.	114	15.4	?	182	8.6	70	225	8.0	62	255	8.6	53	277	8.9	44	299	9.1	32	325	9.0	15
170 W.	110	21.2	?	177	15.0	71	220	13.5	63	250	12.5	55	274	11.3	46	296	10.2	35	324	9.0	18
160 W.	102	27.7	80	171	20.9	72	215	17.8	64	247	15.4	57	273	13.0	48	296	10.6	37	324	8.8	20
150 W.	93	35.0	80	163	26.0	73	208	21.4	66	245	17.7	59	275	14.1	50	299	10.9	38	325	8.8	22
140 W.	81	44.5	?	150	30.9	75	200	24.1	68	244	19.2	61	278	15.0	52	304	11.2	40	328	?	24
130 W.	67	54.6	?	130	35.6	77	190	25.9	70	240	19.8	62	282	15.2	53	310	11.6	41	332	9.1	25
120 W.	47	62.8	85	109	37.7	80	177	25.8	72	233	19.2	64	282	14.6	55	313	11.4	43	334	9.3	26
110 W.	33	70.0	?	87	32.6	82	156	22.3	75	221	16.8	67	280	13.3	57	314	10.7	44	336	9.3	28
100 W.	13	60.0	?	63	17.6	84	134	15.0	77	207	12.7	69	272	10.0	59	312	9.0	46	335	8.6	31
90 W.	19	*67.3*	?	47	*3.0*	85	121	2.1	78	192	5.0	71	259	6.2	62	304	6.4	49	329	7.1	33
80 W.	40	*74.0*	?	58	*30.0*	84	119	*13.6*	78	184	*4.4*	72	245	0.0	63	292	2.7	52	320	4.8	36
70 W.	58	*73.0*	85	76	*41.7*	82	127	*24.0*	77	185	*13.3*	71	235	*6.3*	63	275	*2.3*	52	305	0.7	38
60 W.	70	*67.7*	?	94	*44.4*	80	138	*31.0*	76	188	*19.6*	70	231	*13.0*	62	265	*8.0*	53	291	4.8	40
50 W.	82	*59.0*	?	111	*43.2*	78	152	*32.5*	74	195	*24.0*	68	233	*18.0*	60	264	*13.6*	51	286	*10.9*	40
40 W.	91	*50.0*	80	124	*39.5*	76	163	*31.3*	72	204	*24.8*	66	239	*20.6*	57	267	*18.0*	48	288	*16.2*	36
30 W.	100	*40.3*	?	134	*34.9*	75	173	*28.0*	70	215	*22.8*	63	248	*20.0*	54	277	?	43	?	*19.0*	28
20 W.	107	*33.6*	?	142	*28.8*	73	183	*23.3*	68	225	*19.7*	61	261	*18.1*	50	291	*18.0*	36	302	*19.5*	18
10 W.	?	*26.3*	?	148	*22.2*	72	189	*18.6*	66	233	*15.7*	58	273	*14.6*	46	301	*14.7*	30	311	*16.8*	10

Lat.	0°			10° S.			20° S.			30° S.			40° S.			50° S.			60° S.		
Long.	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*
0° E.	290	*16.1*	*17*	246	*20.4*	*33*	209	*25.1*	*44*	188	*28.0*	*51*	181	*28.2*	*55*	184	*25.2*	*59*	189	*22.1*	*62*
10 E.	294	*12.0*	*22*	245	*16.6*	*38*	205	*22.0*	*50*	180	*26.5*	*56*	169	?	*60*	169	*27.5*	*62*	178	*25.1*	*64*
20 E.	297	*8.2*	*23*	245	*12.9*	*41*	203	*18.4*	*52*	172	*23.7*	*59*	158	*27.7*	*62*	159	*29.0*	*65*	168	*27.3*	?
30 E.	303	*5.5*	*23*	250	*9.4*	*41*	204	*14.6*	*54*	168	*20.5*	*61*	150	*26.0*	*64*	153	?	?	160	*29.3*	?
40 E.	313	*2.2*	*22*	258	*5.7*	*41*	208	*10.7*	*54*	169	*17.0*	*61*	?	*24.4*	*65*	?	*29.8*	?	?	*32.3*	?
50 E.	325	*0.6*	*21*	270	*3.4*	*40*	220	*8.9*	*53*	176	*15.6*	*61*	150	*24.5*	*65*	?	*32.2*	?	?	*37.1*	?
60 E.	338	*2.0*	*19*	285	*5.0*	*38*	234	*10.3*	*52*	188	*18.0*	*61*	161	*27.1*	*65*	?	*36.0*	?	?	*41.6*	*70*
70 E.	350	*4.3*	*19*	301	*7.2*	*38*	247	*13.7*	*52*	203	*21.6*	*61*	175	*30.4*	*66*	161	*39.7*	*68*	?	*46.7*	*72*
80 E.	360	*4.6*	*20*	316	*8.0*	*38*	261	*14.0*	*52*	215	*22.5*	*62*	186	*32.5*	*67*	166	*42.5*	*70*	?	*51.1*	*74*
90 E.	373	*3.0*	*20*	330	*5.7*	*39*	276	*11.0*	*53*	224	*19.5*	*62*	188	*30.4*	*68*	162	*42.1*	*73*	141	*54.3*	*76*
100 E.	384	*0.6*	*20*	342	2.3	*38*	290	*6.5*	*53*	233	*13.3*	*63*	188	*24.6*	*70*	148	*38.6*	*75*	124	*54.7*	*78*
110 E.	389	1.4	*19*	353	0.4	*37*	303	*1.9*	*52*	244	*7.4*	*63*	188	*15.2*	*72*	135	*30.6*	*77*	105	*52.3*	?
120 E.	387	2.4	*17*	360	2.2	*36*	314	0.6	*51*	253	*2.4*	*63*	190	*7.3*	*72*	127	*18.5*	*78*	87	*43.2*	?
130 E.	382	3.0	*16*	364	3.5	*34*	325	3.1	*49*	265	2.0	*62*	197	*0.4*	*71*	128	*5.9*	*78*	?	*25.0*	?
140 E.	?	4.0	*14*	367	4.8	*32*	332	5.2	*48*	275	5.5	*61*	207	5.5	*70*	137	4.0	*77*	?	0.0	?
150 E.	?	5.3	*12*	?	6.3	*31*	336	7.1	*46*	284	8.2	*60*	219	9.7	*69*	151	12.1	*76*	86	14.4	?
160 E.	360	6.9	*10*	?	7.9	*28*	338	9.0	*44*	291	10.5	*58*	231	13.3	*67*	166	16.6	*75*	100	21.6	?
170 E.	355	?	*7*	?	8.9	*25*	339	10.2	*43*	295	12.3	*56*	242	15.5	*65*	182	19.2	*73*	118	26.9	*80*
180 E.	352	?	*4*	360	9.3	*23*	340	10.7	*40*	297	13.1	*54*	251	16.5	*63*	195	20.4	*71*	133	28.8	*78*
170 W.	349	?	0	?	9.4	*21*	338	11.0	*38*	300	13.5	*52*	258	16.7	*62*	204	20.7	*70*	145	29.6	*77*
160 W.	346	?	1	?	9.3	*19*	333	11.1	*36*	302	13.6	*50*	264	16.7	*60*	211	20.8	*68*	158	29.7	*75*
150 W.	?	?	3	344	9.3	*17*	327	11.1	*35*	303	13.6	*48*	268	16.8	*58*	218	20.9	*66*	169	29.8	*74*
140 W.	?	?	4	337	9.4	*16*	322	11.2	*33*	302	13.6	*46*	272	16.8	*57*	227	21.3	*65*	182	30.1	*72*
130 W.	?	?	6	333	9.5	*15*	318	11.3	*32*	301	13.8	*45*	274	17.1	*55*	237	22.0	*64*	196	31.4	*71*
120 W.	?	?	7	330	9.7	*13*	314	11.6	*30*	298	14.2	*43*	275	17.9	*53*	248	23.1	*62*	212	32.7	*69*
110 W.	341	9.1	9	324	10.0	*11*	309	12.0	*28*	294	15.2	*41*	276	19.2	*52*	255	24.4	*60*	226	33.1	*67*
100 W.	337	9.4	12	318	10.6	*8*	302	12.9	*25*	289	16.3	*38*	277	20.5	*48*	262	25.4	*57*	239	32.0	*64*
90 W.	330	8.8	15	310	10.5	*4*	292	13.2	*21*	282	16.6	*35*	?	20.5	*45*	268	24.4	*54*	250	28.8	*61*
80 W.	320	6.6	18	298	9.0	0	280	11.3	*16*	271	15.0	*30*	269	18.3	*41*	270	21.1	*50*	256	25.0	*58*
70 W.	308	2.7	23	286	5.0	6	270	7.4	*11*	259	10.3	*26*	260	13.6	*37*	265	16.6	*47*	257	20.0	*56*
60 W.	295	*3.8*	25	278	*0.9*	8	260	1.0	*8*	248	3.7	*22*	250	6.7	*34*	258	10.1	*44*	?	13.6	*53*
50 W.	291	*9.2*	25	272	*8.2*	8	250	*6.8*	*8*	237	*4.8*	*22*	239	*1.0*	*33*	250	3.1	*43*	249	7.0	*53*
40 W.	291	*15.3*	20	268	*15.1*	2	243	*14.5*	*12*	228	*12.3*	*26*	227	*9.1*	*35*	237	*4.6*	*44*	237	0.4	*53*
30 W.	290	*19 5*	11	263	*20.0*	*5*	236	*19.8*	*21*	218	*18.6*	*32*	214	*15.7*	*39*	224	*11.5*	*47*	224	*6.4*	*54*
20 W.	289	*21.1*	1	257	*22.6*	*15*	227	*23.7*	*30*	209	*23.6*	*38*	203	*21.0*	*45*	209	*17.0*	*51*	211	*12.7*	*57*
10 W.	289	*19.6*	*8*	250	*23.1*	*25*	218	*25.6*	*37*	198	*27.0*	*45*	192	*25.4*	*51*	197	*21.7*	*55*	199	*17.8*	*59*

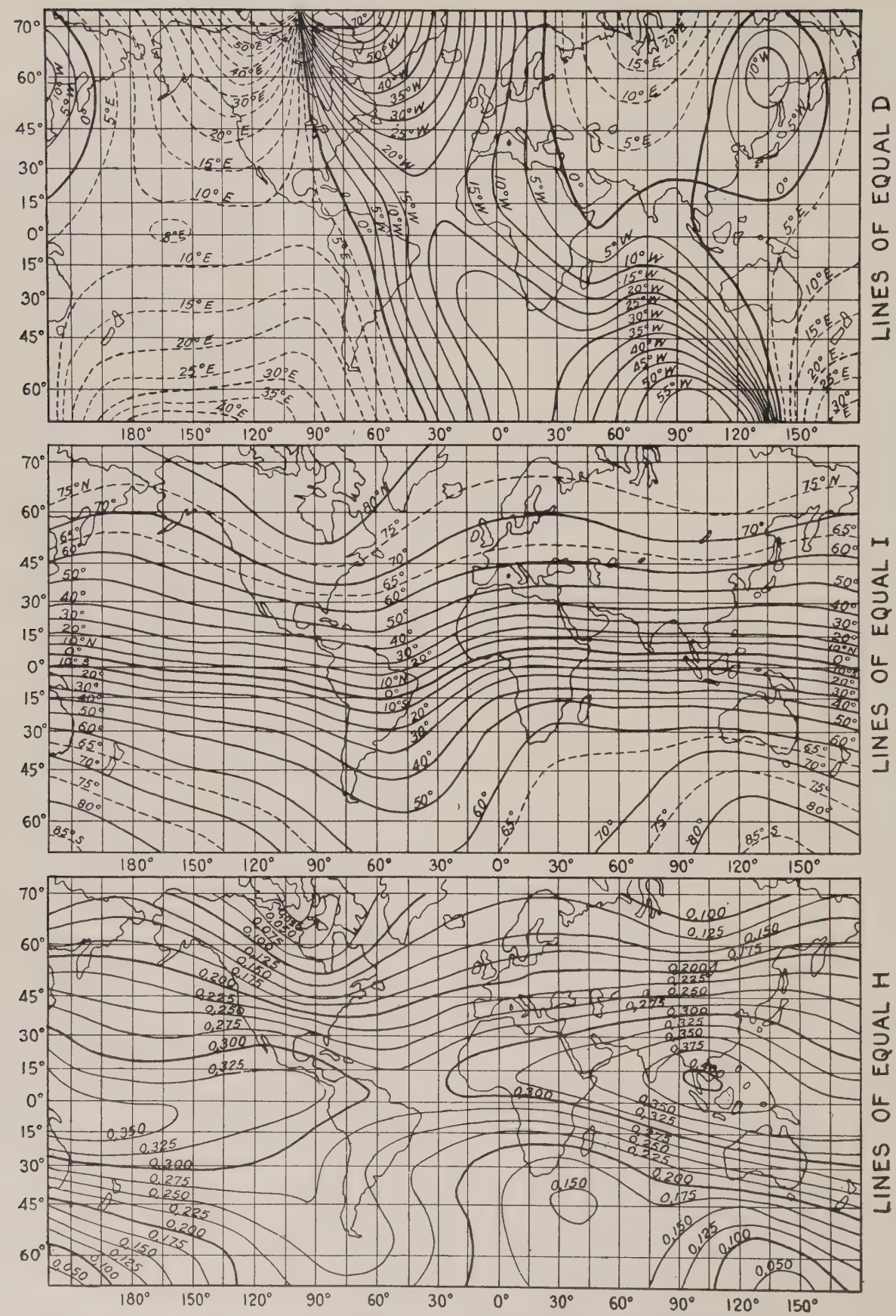

FIG. 1.—Curves of equal declination (D), of equal inclination (I), and of equal horizontal intensity H: for 1922 (6). Based on British Admiralty Charts for 1922. Values are marked on the curves; unit of H = 1 gauss = 1 cgsm unit.

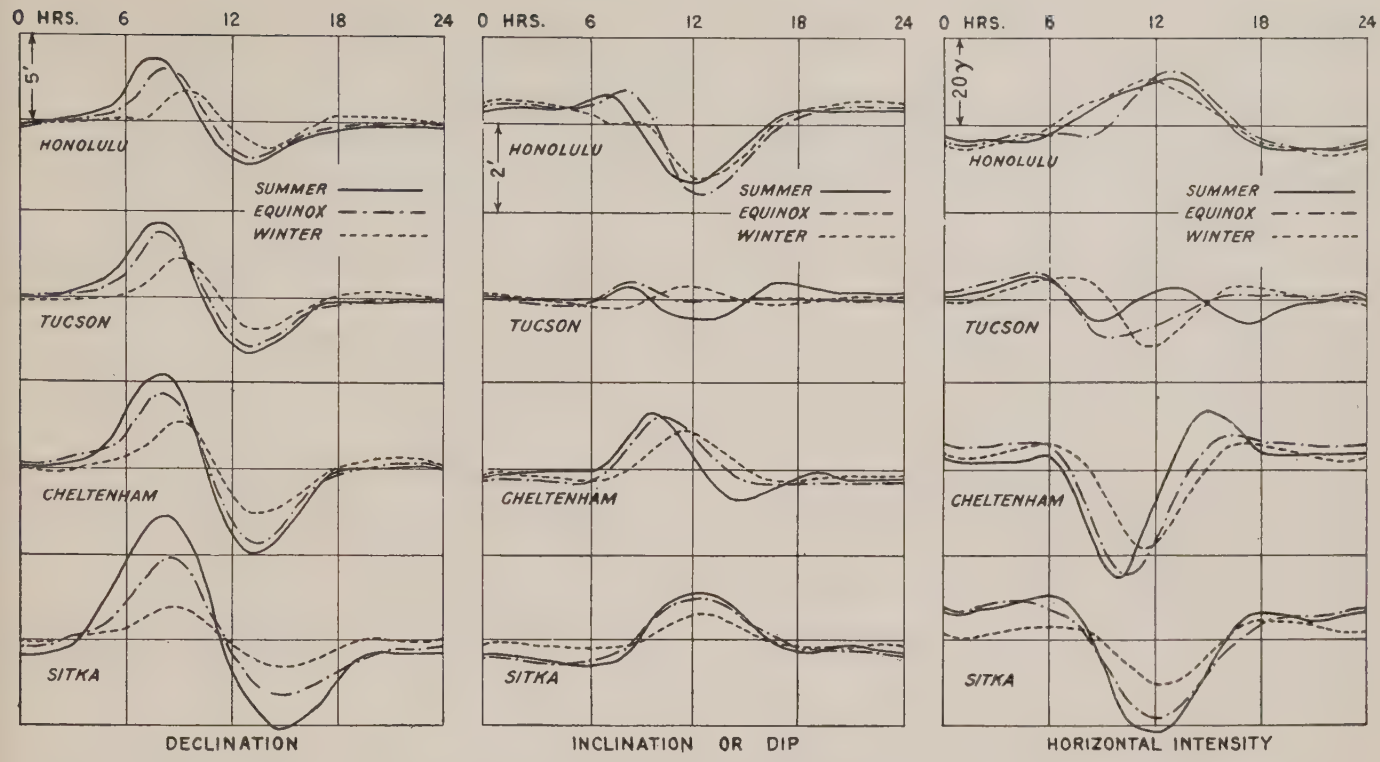

FIG. 2.—Diurnal variations at selected stations [10].

Data are based on average values for stormless days. Time is measured from local mean noon; $1\gamma = 10^{-5}$ gauss $= 10^{-5}$ cgsm unit.

TABLE 4.—SECULAR CHANGES IN DECLINATION (D) AT VARIOUS PLACES, AND OVER LONG PERIODS [10]

For recent variations, *see* Table 5; south and west values are printed in *italics*

Lat.	51° 28′	44° 55′	37° 48′	23° 07′	14° 36′	12° 04′	22° 54′	33° 56′
Long.	0 19	67 00	122 27	82 22	120 58	77 08	43 10	18 29
Place	London, England	Eastport, Maine	San Francisco, California	Havana, Cuba	Manila, P. I.	Callao, Peru	Rio de Janeiro, Brazil	Cape Town, S. Africa
Year	D							
1540	7.2°							
1560	9.6							
1580	10.9							
1600	10.1							1.0°
1620	7.3	*19.0°*						*1.5*
1640	3.3	*18.5*						*4.0*
1660	*0.6*	*17.5*					12.1°	*6.4*
1680	*3.9*	*16.0*					11.8	*8.9*
1700	*7.1*	*14.5*					11.3	*11.5*
1720	*11.0*	*13.1*		4.0°		6.7°	10.6	*14.0*
1740	*15.3*	*12.4*		5.0		7.7	9.7	*16.8*
1760	*19.6*	*12.2*		5.8	*0.1°*	8.6	8.5	*19.4*
1780	*22.7*	*12.4*	12.6°	6.3	0.0	9.4	7.1	*22.2*
1800	*24.1*	*13.2*	13.6	6.5	0.1	10.0	5.5	*25.0*
1820	*24.1*	*14.7*	14.6	6.3	0.2	10.4	3.5	*27.1*
1840	*23.2*	*16.3*	15.4	6.0	0.3	10.6	1.2	*29.0*
1860	*21.5*	*18.0*	16.1	5.2	0.5	10.5	*1.5*	*30.0*
1880	*18.7*	*18.8*	16.5	4.0	0.7	10.3	*4.4*	*29.8*
1900	*16.5*	*19.3*	16.9	3.1	0.9	9.9	*7.7*	*28.6*
1910	*15.7*	*20.0*	17.6	3.0	0.8	9.2	*9.5*	*27.5*
1920	*14.1*	*20.8*	17.9	3.4	0.7	8.5	*11.2*	*26.1*

TABLE 5.—SECULAR CHANGES IN MAGNETIC ELEMENTS AT VARIOUS OBSERVATORIES: 1905 TO 1925 [10]

Z = total intensity, D = declination (east or *west*), I = inclination (north-seeking pole down). West values are printed in *italics*. Δ = algebraic excess above value in column 1905; *e.g.*, at Sitka in 1915, $Z = 58\,797 - 659 = 58\,138$, $D = 29°\ 59.1' + 24.1' = 30°\ 23.2'$, $I = 74°\ 43.2' - 16.7' = 74°\ 26.5'$. Unit of $Z = 1\gamma = 10^{-5}$ gauss $= 10^{-5}$ cgsm unit.

Year	1905	1910	1915	1920	1925
Place	Value	Δ			
Sitka	Z 58 797	−371	−659	−997	−1 177
57° 03′ N.	D 29° 59.1′	+17.3′	+24.1′	+29.1′	+28.1′
135° 20′ W.	I 74° 43.2′	−11.0′	−16.7′	−21.1′	−21.0′
Greenwich	Z 47 274	−34	−171	−252	−424
51° 28′ N.	D *16° 09.9′*	*−28.7′*	*−1° 13.4′*	*−2° 01.3′*	*−2° 59.9′*
0° 00′	I 66° 55.9′	−3.3′	−4.1′	−2.3′	−4.4′
Toronto	Z 61 730	−309	−935	−1 439	
43° 40′ N.	D *5° 42.2′*	*+21.7′*	*+46.3′*	*+1° 03.2′*	
79° 24′ W.	I 74° 34.3′	+4.2′	+8.6′	+10.3′	
Cheltenham	Z 59 878	−282	−896	−1 380	−1 895
38° 44′ N.	D *5° 17.8′*	*+23.6′*	*+46.2′*	*+1° 00.7′*	*+1° 21.4′*
76° 50′ W.	I 70° 25.4′	+10.0′	+21.4′	+30.0′	+35.1′
Tucson	Z 53 669	Values for 1910	−374*	−712*	−1 072*
32° 15′ N.	D 13° 25.8′		+16.7′*	+22.2′*	+19.5′*
110° 50′ W.	I 59° 19.6′		+5.1′*	+8.0′*	+11.0′*
Honolulu	Z 38 168	−258	−587	−827	−1 006
21° 19′ N.	D 9° 21.7′	+8.0′	+19.9′	+31.5′	+40.1′
158° 04′ W.	I 40° 05.0′	−17.8′	−35.9′	−39.9′	−39.1′
Vieques	Z 44 795	−61	−85	−213	
18° 09′ N.	D *1° 38.3′*	*+42.3′*	*+1° 31.8′*	*+2° 07.8′*	
65° 27′ W.	I 49° 17.0′	+35.0′	+1° 28.9′	+2° 05.7′	

* Algebraic excess over value for 1910.

Earth Currents.—It is not practicable to do more than to indicate the order of magnitude of earth currents. At the observatory del Ebro, Tortosa, Spain, the horizontal electrical potential gradient in the earth was measured over a distance of 1.28 km in a north-south line, and over a distance of 1.40 km in a west-east line. The average of observations extending over 4 yr (1914–18) gave as the gradient along the N.-S. line 0.204 volt per km, current (+) from N. to S., and along the W.-E. line 0.114 volt per km, current (+) from W. to E.

Aurora.—Auroral activity is confined largely to two zones of the atmosphere situated at an angle of about 20° to the magnetic polar axis. The lower edge of the aurora is sharply bounded; the height of this boundary appears to vary from 70 to 300 km, with a maximum number at about 115 km.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *B95*, Vol. 15. (2) Auerbach, *B90*, Vol. 4. (3) Bauer, *268*, **25**: 145; 20. (4) Bauer, *268*, **28**: 1; 23. (5) British Admiralty Charts. (6) Bur. Central Magn. Terr. *Atlas magnétique.* Paris, Maurin, 1905. (7) Chree, *Encycl. Brit.*, 11th ed., **17**: 353; 10. (8) Dyson and Furner, *520, Geophys. Suppl.*, **1**: No. 3; 23. (9) Fleming, *Trans. Sect. Terr. Mag. Elec., Intern. Geophys. Union*, Madrid, 1925. Bull. 5.
(10) Hazard, *217*, **No. 117**; 25. (11) Nippoldt, in Müller-Pouillets, *Lehrbuch der Physik und Meteorologie*, Vol. 4. 1914. (12) Schmidt, *Enzykl. math, Wiss.*, Vol. 6; 18. (13) Schmidt, *Z. Geophysik*, **1**: 281; 25. (14) Swann. *Encycl. Brit.*, 1927.

In addition to the references specifically cited, *see* also (1, 2, 7, 11, 12, 14), and the following publications: Publications of the magnetic observatories listed in Table 2, Researches of Department of Terrestrial Magnetism of Carnegie Institution of Washington, J. Terr. Mag. and Atm. Elec., B. A. A. S. Reports, Proc. Roy. Soc., Phil. Trans., Monthly Notices R. A. S., Meteorolog. Z., Physik. Z., Trans. Sect. Terr. Mag. and Elec. of Intern. Geophys. Union.

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George Walter Stewart, Special Editor

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PHYSICAL ASPECTS OF AUDITION

H. Fletcher

For general bibliography of speech and hearing, *see* (6)

SYMBOLS AND DEFINITIONS

d.v. Double (or complete) vibration(s).
E Physical intensity of a sound = power (energy per second) it transmits per a unit of area normal to direction of propagation.
N Frequency = number of d.v. per unit of time.
P Amount by which the r.m.s. pressure exceeds the static pressure; P_0 = threshold value of P for an average normal ear; it depends upon N; P_m = value of P required for audition in presence of a masking tone.
r.m.s. Root-mean-square; r.m.s. pressure = square root of the time average of (pressure)^2.
S Sensation level.
sen Sensation unit.
t Time.
v.p.s. Vibrations per second; 1 v.p.s. = 1 d.v. per sec.
φ Phonic level.

Masking of a tone (A) by another (B) means the difficulty in distinguishing A when sounded simultaneously with B. It is expressed by the difference in phonic level between P_m and P_0, this equals $20 \log_{10} (P_m/P_0)$ sen. (*See* Figs. 2, 3, 4.)

Phonic level of P above the fixed datum corresponding to P' is $\varphi_p = 20 \log_{10} (P/P')$ sen. In this section P' is taken as 1 dyne cm^{-2}. (*Cf.* Sensation unit.)

Sensation level (S) measures the auditory intensity of sound; it is the excess of the phonic level above that of P_0. For a pure tone, $S = \varphi_P - \varphi_{P_0} = 20 \log_{10} (P/P_0)$ sen.

Sensation unit (sen) is defined as that fractional change in intensity which is just perceptible by the ear. Throughout the range of audition, it is found that if the sensation being experienced is that corresponding to $P = P_1$, then the smallest perceptible change is approximately $\frac{1}{20}$ of that caused by increasing P from P_1 to $10P_1$. Hence in the range P_1 to P_2 there are $20 \log_{10} (P_2/P_1)$ sen. It is convenient to regard this relation as extending indefinitely, irrespective of the range of audition, and to regard each value of P as corresponding to a phonic level of $20 \log_{10} (P/P')$ sen above some convenient fixed datum (P') which is independent of the auditor and audition. (*Cf.* (5).)

Sensitivity of the ear is inversely proportional to P_0; the unit is so chosen that the sensitivity = $1/P_0$.

Threshold value (P_0) of P for any given auditor and tone is that least value of P, in the ear canal, which produces an audible sound of that tone.

Table 1.—Sensitivity of the Ear

See also Vol. I, p. 94

Absolute Sensitivity = $1/P_0$.—*Differential sensitivity* is the reciprocal of the least perceptible fractional change ($\Delta E/E$, $\Delta N/N$) in E or N. Sensitivity in recognition of pitch may be taken as the reciprocal either of the time the tone must persist, or of the total number of d.v. that must reach the ear, in order that the tone shall be recognized.

Unit of N = 1 v.p.s.; of P_0 = 1 dyne/cm^2; of t = 1 sec; of S = 1 sen.

Limits of Audibility (6).—Lower limit varies from N = 8 to 40; upper, from N = 12 000 to 35 000.

Absolute sensitivity ([9, 13, 20]); *see also* Fig. 1.

N	64	128	256	512	1024	2048	4096
P_0	0.12	0.021	0.0039	0.0010	0.00052	0.00041	0.00042

Differential sensitivity for monaural reception of successive tones ([12, 14]).

$\Delta E/E$ depends upon both S and N, and is given by the empirical equation $\Delta E/E = (\Delta E/E)_\infty + \{(\Delta E/E)_t - (\Delta E/E)_\infty\} \times 10^{-rS/10}$, where $(\Delta E/E)_\infty = 126/\{80N^{0.5} + N\} + 0.000015N$, $(\Delta E/E)_t = 0.3 + 0.003N + 193/N^{0.8}$, and $r = 0.244 \times 10^6/\{358\,000N^{0.125} + N^2\} + 0.65N/\{3500 + N\}$.

$\Delta N/N$ varies with S about as $\Delta E/E$ does. For $S = 40$ sen, $\Delta N/N$ varies with N thus:

N, v.p.s.	64	128	256	512	768 to 4096
$\Delta N/N$, %	0.93	0.59	0.4	0.32	0.3

Pitch Recognition ([1]).—t and d.v. = least duration of the tone, and smallest number of d.v. received, consistent with recognition of the tone.

E	Weak			Medium		
N	128	384	512	256	384	512
t	0.0946	0.0627	0.0579	0.0691	0.0445	0.0427
d.v.	12.1	24.1	29.6	17.6	17.1	21.8

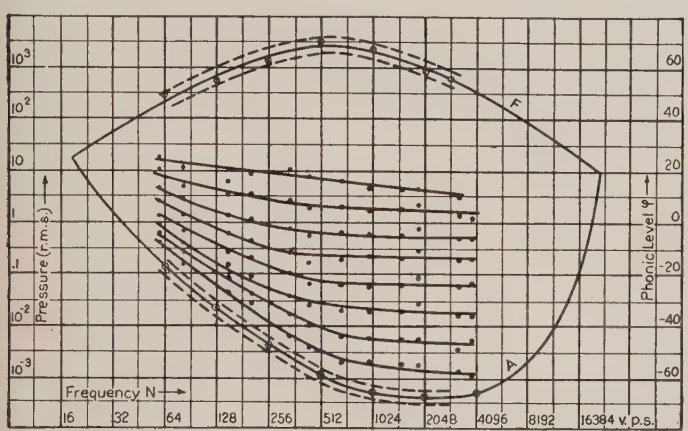

FIG. 1.—Phonic levels (φ) for equality of loudness of pure tones.

Threshold values of audibility are shown by curve A (weighted mean ([7, 9, 13]), pitch limits range ([6]) from $N = 8$ to 40 and from $N =$ 12 000 to 35 000), of feeling, by curve F ([18]); half of observations lie between the dotted curves. Interior curves are contour lines of equal loudness, reference tone being $N = 700$ v.p.s.; each point is average of 3 observations by each of 22 observers; distance from curve A measures the sensation level. φ = phonic level, datum = 1 dyne/cm², unit = 1 sen; unit of pressure = 1 dyne/cm².

Loudness ([8, 11, 16]).—Until recently it was thought that the loudness of a tone is measured by its sensation level, but there is not a strict proportionality between these two quantities. Contour lines of equal loudness for pure tones show that tones below 1000 v.p.s. increase in loudness more rapidly than do tones of higher frequency. (*See* Fig. 1.)

Localization of Pure Tones ([17]).—If 100 v.p.s. $\leqslant N \leqslant$ 1000 v.p.s., then, approximately, $\theta = \psi/(0.8 + 0.0034N)$, if unit of N = 1 v.p.s.; θ = angle the apparent direction of the source makes with median plane of the observer; ψ = angular phase difference of the tone at the two ears. θ and ψ must be expressed in the same unit; positive direction of θ is from the front towards the ear of the leading phase.

Miscellaneous Aural Data.—Minimum audible power = $4(10)^{-}$ microwatt/cm² ([9, 13, 20]). Ear canal: Length = 2.1 to 2.6 cm, volume = 1 cm³, area of open end = 0.33 to 0.50 cm². Drum. Diameter = 0.85 cm vertical, 1.00 cm horizontal; area = 0.65 cm². Hammer: Length = 0.8 to 0.9 cm; weight = 23 mg. Anvil weighs 25 mg. Stirrup weighs 3 mg ([10, 21]). Mechanical impedance of drum ([7]) for N = 200 to 4000 v.p.s. = 20 to 30 dyne/(cm per sec); that is, a value of P corresponding to an r.m.s. periodic force of 20 or 30 dyne is required to impart to the drum an effective r.m.s. velocity of 1 cm/sec, the effective

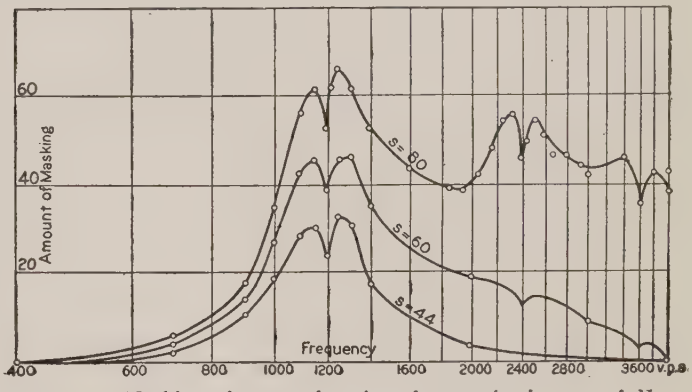

FIG. 3.—Masking of tones of various frequencies by one of N = 1200 v.p.s. and of sensation level = 44, 60 or 80 sen: Both tones sounded in same ear ([19]).

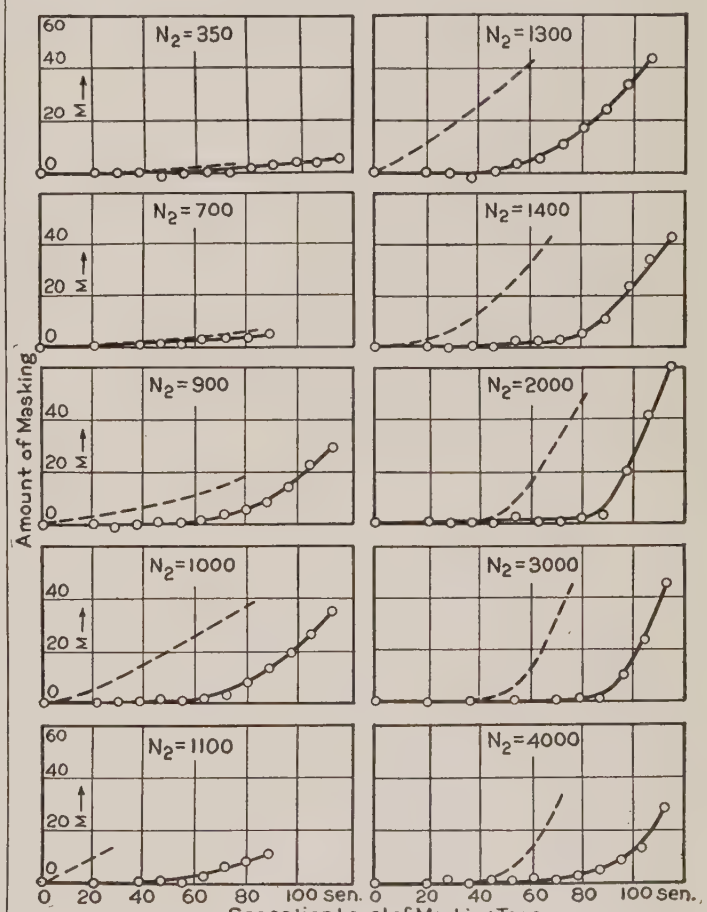

FIG. 4.—Masking of tones N_2 by tones of N = 1200 v.p.s. of various intensities: Tones sounded in opposite ears ([19]).

Tones introduced by telephone receivers. Dotted lines are from Fig. 2. Attenuation introduced by the skull from ear to ear is such that in monaural reception the phonic levels at the two ears differ by 40 or 50 sen. M = amount of masking. Unit of N_2 = 1 v.p.s.; of M and of sensation level = 1 sen.

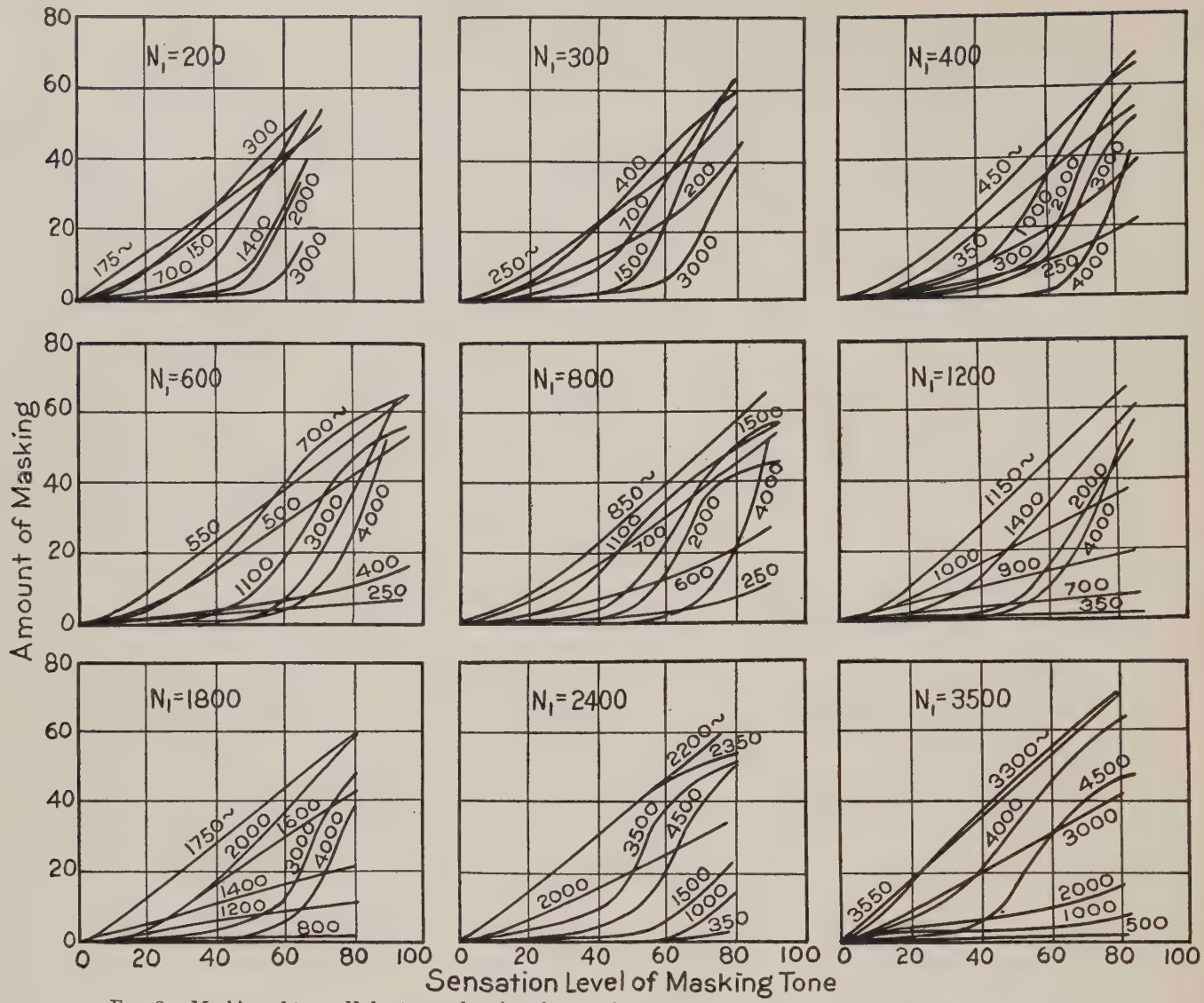

FIG. 2.—Masking of tones N_1 by tones of various frequencies and intensities: Both tones sounded in same ear [19]. Frequency (N) of masking tone is marked on curve; unit of N and N_1 = 1 v.p.s.; of masking and sensation level = 1 sen.

velocity ($\bar{v}$) being defined as $\bar{v} = \frac{1}{A}\int_0^A v\,da$, A being the area of the drum and da being an element of area at which the velocity is v.

Recognition of English Speech [4].—In order that at least 50 % of the spoken syllables shall be recognized: (1) S must be $\geq$ 25 sen if the sound is undistorted. (2) If S = 60 to 80 sen and the sound is distorted either by the removal of all frequencies above $N = N_1$, or of all below $N = N_2$, then N_1 must be >1200 v.p.s. and N_2 <1800 v.p.s. (*See* Fig. 5.)

Speech Power [7].—Mechanical speech power delivered by average speaker = 10 microwatt; if exclude silent intervals, it is 14 microwatt. Peak power frequently rises to 1000 microwatt. For unaccented vowels, average power in the particular cycle carrying the maximum energy is 35 microwatt; for accented vowels, it is 105 microwatt; instantaneous peak powers are 16 times average power [15]. Telephonic speech power = electrical power output of a commercial telephone subset during a normal telephone conversation. For individual variations, *see* Fig. 6; for distribution of power among the tones, *see* Fig. 7.

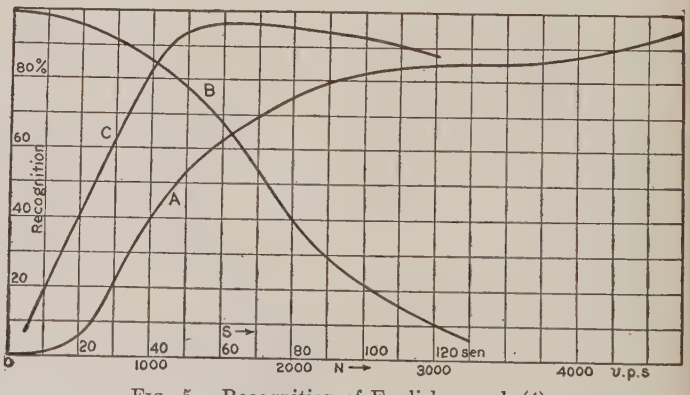

FIG. 5.—Recognition of English speech [4].

Recognition = relative number of syllables recognized. For curve A, all frequencies above N are eliminated; for B, all those below N; C shows effect of sensation level (S) upon recognition of the undistorted sounds. For A and B, S = 60 to 80 sen.

TABLE 2.—RELATIVE FREQUENCY (F) OF OCCURRENCE OF SOUND ELEMENTS OF ENGLISH SPEECH (3)

Sound = sound element; Key = English word containing the sound; unit of F = 1 % of total

Sound	Key	F	Sound	Key	F
a	top	3.3	h		1.81
ā	tape	1.84	j		0.44
á	tap	3.95	k		2.71
e	ten	3.44	l		3.74
ē	eat	3.12	m		2.78
er	term	0.63	n		7.24
i	tip	8.53	ng	hang	0.96
ī	dike	1.59	p		2.04
o	ton	6.33	r		6.88
ō	tone	1.63	s		4.55
ó	talk	1.35	sh	shell	0.87
u	took	0.71	th	tooth	0.37
ū	tool	1.89	th	then	3.43
ou	our	0.59	t		7.13
b		1.81	v		2.28
ch	chalk	0.52	w		2.08
d		4.31	y		0.60
f		1.84	z		2.97
g		0.74	Total		100.00

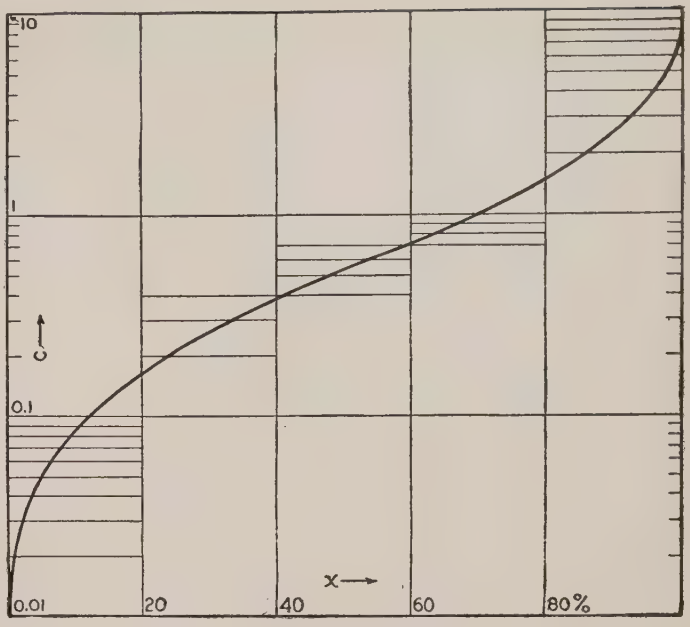

FIG. 6.—Variation in telephonic speech power of individuals (7). x = percentage of speakers having telephonic speech power $\gtrless CA$, where A = average power of all speakers.

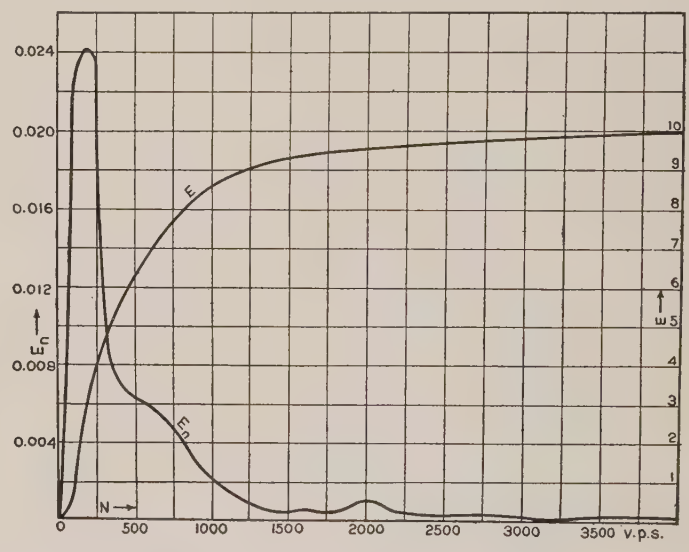

FIG. 7.—Distribution of power in average spoken English (2). Total power carried by all the tones from $N = 0$ to $N = n'$ is $E = \int_0^{n'} E_n dn$, where $E_n dn$ = power carried by the tonal region $N = n - \frac{1}{2}dn$ to $N = n + \frac{1}{2}dn$. Unit of E_n = 1 microwatt per v.p.s.; of E = 1 microwatt; of n, n', N = 1 v.p.s.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bode, *Psychologische Studien*, (*Wundt*), **2**: 293; 07. (2) Crandall and MacKenzie, *2*, **19**: 221; 22. (3) Dewey, *The relative frequency of English speech sounds*, Cambridge, Harvard Univ. Press, 1923. (4) Fletcher, *143*, **193**: 729; 22. (5) Fletcher, *143*, **194**: 289; 23. (6) Fletcher, *143*, **194**: 323; 23. (7) Fletcher, *Bell System Tech. J.*, **4**: 375; 25. (8) Fletcher and Steinberg, *2*, **24**: 306; 24. (9) Fletcher and Wegel, *2*, **19**: 553; 22.
(10) Howell, *Text-book of physiology*. Philadelphia, Saunders, 1924. (11) Kingsbury, *2*, **29**: 588; 27. (12) Knudsen, *2*, **21**: 84; 23. (13) Kranz, *2*, **21**: 573; 23. (14) Riesz, Bell Telephone Laboratories, N. Y., *0*. (15) Sacia, Bell Telephone Laboratories, N. Y., *0*. (16) Steinberg, *2*, **26**: 507; 25. (17) Stewart, *2*, **15**: 425, 432; 20. (18) Wegel, *Bell System Tech. J.*, **1**: 56; 22. (19) Wegel and Lane, *2*, **23**: 266; 24.
(20) Wien, *278*, **97**: 1; 03. (21) Wrightson, *Enquiry into the mechanism of the internal ear*. New York, Macmillan, 1918.

SOUND-GENERATORS

F. R. WATSON

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DEFINITIONS AND SYMBOLS

Amplitude.—The amplitude of the oscillation of a point is its extreme departure from that condition of rest about which the oscillations occur. If the departure (y) at the time τ satisfies the equation $y = A \sin(n\tau + \epsilon)$, A is the amplitude.

Frequency.—The frequency of an oscillation is the number of vibrations per unit of time.

Period.—The period of an oscillation is the time required for one vibration; it is the reciprocal of the frequency.

Vibration.—In each interval between successive returns of the body to exactly the same phase of its motion, it executes a single vibration. For example, from the instant a pendulum bob passes from left to right through the lowest point of its arc to the

next instant in which it passes in the *same* direction (left to right) through the same point is the interval occupied by a single vibration of the pendulum.

a	Thickness in the plane of vibration.
E	Young's modulus of elasticity.
F	Tensile force.
l	Length.
N	Frequency.
N_i, N_o, N_t	Frequency for ideal case, at 0°C, at t, °C.
p	Pressure.
r, r_o	Radius, value of r at 0°C.
t	Temperature, °C.
v.p.s.	Vibrations per second.
ρ, ρ_0	Density, value of ρ at 0°C.
σ	Mass per unit of length.

Other symbols will be defined where used.

SOUND-GENERATORS

Of the sound-generators, exclusive of musical instruments, only those that are most commonly used or that appear to be useful are considered here. They may be classified as follows:

I. Strings and strips: (*A*) Transverse vibrations: (1) Plucked string. (2) Ribbon loud-speaker. (*B*) Longitudinal vibrations: (3) Stretched wires. (4) Berger's hydrophone.

II. Rods and forks: (5) Tuning fork.

III. Plates and diaphragms: (*A*) Electromagnetic drive: (6) Telephone receiver. (7) Hewlett's generator. (8) Loud-speaker. (9) Fessenden's hydrophone oscillator. (*B*) Electrostatic drive: (10) Electrostatic transmitter. (*C*) Mechanical drive. (11) Piston-phone. (*D*) Piezoelectric generator: (12) Quartz (SiO_2). (13) Rochelle salt ($KNaC_4H_4O_6.4H_2O$). (*E*) Free elastic vibrations: (14) Bell.

IV. Confined fluid: (15) Organ pipe. (16) Tonvariator. (17) Galton's pipe. (18) Singing tube. (19) Thermophone.

V. Free fluid: (20) Siren. (21) Diaphone. (22) Explosives.

Of the preceding generators, numbers 2 and 8 are especially suited for the intense emission of spoken sounds, and numbers 4, 9, 14, and 22 are suitable for the emission of sound under water.

Descriptions of other generators may be found in (**3, 4, 5, 9, 10, 18, 47, 49, 54, 59**).

1. *Plucked String* (**3, 39**).—If the string is perfectly flexible, $N_i = n/2l\sqrt{F/\sigma} = n/2l\sqrt{F(1+\alpha t)/\pi r_0^2\rho_0}$, if l, the distance between the bridges, is independent of t. Here n is the number of loops in the length l, n may have any integral value, and α is the coefficient of linear expansion of the string. Actual strings are not perfectly flexible; for them $N = N_i(1 + c)$, where c, the stiffness correction, increases as l is reduced. For a steel wire with r = 0.20$_5$ mm, F constant and such that N = 76 v.p.s. if l = 90 cm, Melde (**39**) found c varied thus:

l	90	45	30	22.5	18 cm
c	0	1.3	1.8	3.9	5.3%

2. *Ribbon Loud Speaker* (**51**).—When a variable electric current flows through a thin, corrugated, metallic ribbon mounted in a magnetic field, the ribbon vibrates, thus generating sound. For such loud speakers, an aluminum ribbon 10 cm long, 1 cm wide, 0.001 cm thick, weight = 30 mg, resistance = 0.05 ohm, is used; its maximum current, voltage, power, and amplitude are 10 ampere, 0.5 volt, 5 watt, and 0.5 cm. When fitted with a horn, the emitted speech was intelligible at a distance of 1 km (**26**).

3. *Longitudinal Vibration of a Stretched Wire* (**12**).—$N_i = 1/2l\sqrt{E/\rho}$ and is independent of F. For a steel wire of l = 676 cm and r = *ca.* 0.2 mm, N was found to be 762 v.p.s.

4. *Berger's Hydrophone* (**50**) consists of 3 steel strips, each 3.84 cm (1.5 in.) wide, 0.16 cm ($\frac{1}{16}$ in.) thick, and about 180 cm (6 ft.) long, attached, below the water-line, to the side of a ship, and set into longitudinal vibration by means of a friction drum driven by a 2.2 kw (3 h.p.) motor. The sound was heard under water to a distance of 6.4 km (4 miles).

5. *Tuning Forks* (**3, 40**).—$N = C\frac{a+\delta_a}{(l+\delta_l)^2}\sqrt{\frac{E}{\rho}}$, where C is a numerical constant, and δ_a, δ_l are corrections which are independent of a and l. For steel forks, $C\sqrt{E/\rho}$ = 81 800, δ_a = 0.05 cm, δ_l = 0.38 cm; l is the projection of the prong on the axis of the fork; N is independent of width perpendicular to plane of vibration. If $-26°C < t < +56°C$, $N_t = N_0/(1 + 0.000134t)$ (**11**); for higher temperatures, *see* Fig. 1. For variation of N with amplitude, *see* Fig. 2. By controlling the temperature and amplitude, and using a specially designed spark-gap, a fork of 25 v.p.s. has been vibrated several hours daily for several weeks without a change exceeding 1 in 10 000 in N (**60**). By means of a circuit containing an oscillating electron tube, forks of N = 50 to 2000 v.p.s. may be kept in vibration without the use of a mechanical contact circuit breaker (**16**).

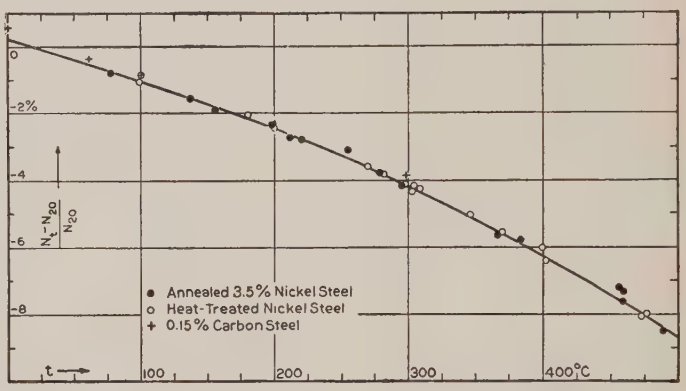

FIG. 1.—Tuning forks: Variation of frequency (N) with temperature (**31**).

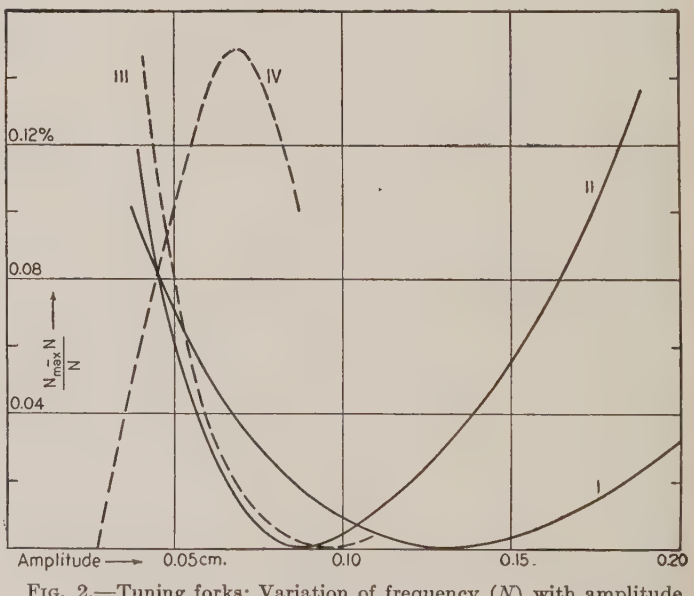

FIG. 2.—Tuning forks: Variation of frequency (N) with amplitude (**11**). The driving current was interrupted by break between spring and point. Curves I and II refer to same fork; for I the amplitude was varied by varying the current, for II it was varied by changing the positions of the pole-pieces of the magnet. Curves III and IV refer to two other forks; the contacts of fork IV were mounted quite differently from those of the others.

6. *Telephone receivers* consist of a circular metallic diaphragm, either of magnetic material or with a plate of such material attached to its center, which is clamped along its circumference and is vibrated by a varying magnetic field. For variation of the amplitude with the frequency of the field, *see* Fig. 3. The over-all efficiency (Eff.) is defined as the ratio of the acoustic energy emitted to the electric energy supplied. For a bipole, 87 ohm, Bell telephone receiver, $N = 992$ v.p.s., no cap over diaphragm, Eff. $= (0.375 \pm 0.025)\%$ [33]. For variation of Eff. with N *see*, Fig. 4. Minimum electrical power required to give a sound audible to a normal ear is of the order of 3.3×10^{-13} watt for a representative type of receiver [55]. For acoustic characteristics, *see* [33].

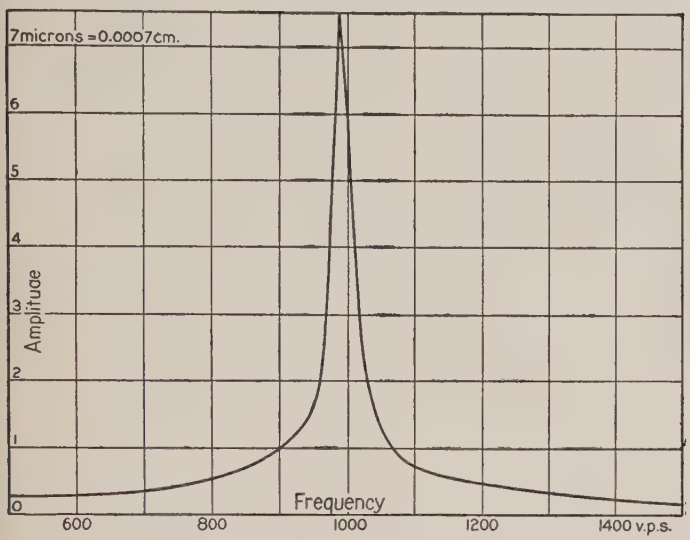

FIG. 3.—Telephone receiver: Variation of amplitude with frequency of current [30].

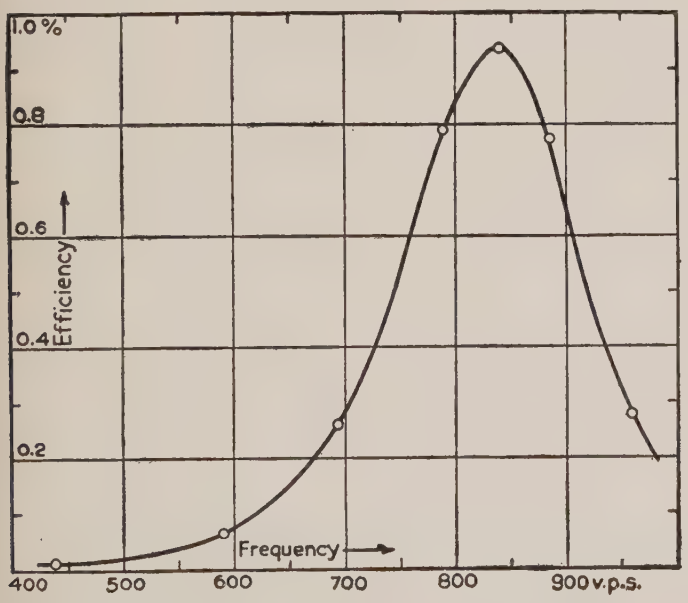

FIG. 4.—Telephone receiver: Variation of acoustic efficiency with frequency of the current [38].

Ordinates are the over-all efficiencies.

7. *Hewlett's tone generator* [27] consists of a thin, circular, metallic diaphragm clamped along its circumference, and placed between two flat circular coils, each wound in its own plane. By a suitable bridge connection, a constant direct current is passed through the coils in such a way as to produce in the diaphragm a radial magnetic field, and at the same time, an alternating current is so passed through them as to produce an axial field. As a result, the diaphragm vibrates with the period of the alternating current. If the diaphragm is nonmagnetic and the current is simply harmonic, the tone is pure. When a certain instrument was excited by a direct current of 1.5 ampere and a voice current of 0.1 ampere, the reproduced speech was comfortably audible at all points in a room 20 ft. square [28]. The amplitude (A) varied thus with the frequency of the alternating current, the strength of the current remaining constant:

N.....	1440	1600	2200	3700	v.p.s.
A.....	4.6	4.16	4.04	1.72	$\times 10^{-5}$ cm

8. *Loud-speaker.*—For general discussion, *see* [13, 44]; for "ribbon" loud-speaker, *see* 2, above. The over-all efficiency varies from 0.1% to 1% [13, 44]. A balanced electromagnetic loud-speaker, diaphragm 7.62 cm (3 in.) in diameter, equipped with a horn, and radiating approximately 1 watt of acoustic energy, was heard loudly at a distance of 0.8 km (0.5 mile) [21]. A loud-speaker equipped with a paper cone of 45°, maximum diameter = 15.25 cm (6 in.), paper 0.18 to 0.25 mm (0.007 to 0.010 in.) thick, had a general sensitivity equal to that of a good horn-type speaker, and responded to both low and high frequencies [48]. Data for loud-speaker horns [19, 22].

9. *The Fessenden hydrophone oscillator* is a diaphragm operated by either an electrodynamic or electromagnetic drive. With the electrodynamic arrangement, a 5 kw. oscillator of 545 kg. wt. (1 200 lb. wt.) has a tuned diaphragm, about 60 cm (2 ft.) in diameter, clamped at the rim, and attached at the center to a light, hollow copper cylinder. This cylinder is mounted in a powerful magnetic field (about 15 000 line/cm^2) so that alternating currents about the core inside the cylinder induce in the copper alternating currents of about 10 000 ampere. The cylinder is thus pushed and pulled with magnetic forces of about 1 800 kg. wt. (4 000 lb. wt.). When suspended 366 cm. (12 ft.) below the surface of open water the sound ($N = 500$ v.p.s.) was detected under water at a distance of 57.4 km [1, 50].

10. *Electrostatic, or condenser, transmitter* [58] consists of an electric condenser composed of a thin (0.051 mm) metal diaphragm and a heavy plate separated by an air layer 0.025 mm thick. The diaphragm is under such radial tension that its natural frequency in air is 7000 v.p.s. An alternating voltage applied to the condenser causes the diaphragm to vibrate with twice the frequency of the voltage. The intensity of the emitted sound is of the same order as that from a telephone receiver. Such a transmitter may be used as a standard source of sound.

11. *Piston-phone* [56, 57].—A rotating cam imparts a simple harmonic motion to a piston which is attached to a diaphragm; $N = 10$ to 200 v.p.s.

12, 13. *Piezoelectric Generator.*—A suitably cut, thin parallelopipedon of a piezoelectric crystal (*see* p. 207) will execute dilatational-rarefactional vibrations when subjected to a transverse alternating electric field. The amplitude of the vibrations is exceedingly small unless the frequency of the field is near that of one of the natural periods of the parallelopipedon. Such plates are useful for generating waves of high pitch.

If the plate is of quartz (SiO_2) and is cut so that its broad faces are perpendicular to an electrical axis and its breadth is parallel to the optic axis, then its length (l) will be perpendicular to each of these axes, and a varying field perpendicular to its broad faces will generate vibrations in the directions of l and of e, the thickness; the natural frequencies, N_l and N_e are given by the equations $lN_l = eN_e = 275\ 000$ cm v.p.s.

Plates of rochelle salt ($KNaC_4H_4O_6.4H_2O$) may be used likewise, and in some respects are superior to those of quartz (7).

14. *Bells* rung under water may be heard under water at a distance of 3 to 5 km (2 to 3 miles) (1, 41).

15. *Organ Pipes.*—The natural pitch of an open organ pipe is $N = \frac{v}{2(l + c + c')}$, and of a closed one is $N = \frac{v}{4(l + c)}$, where c = correction for mouth-end of pipe = $2.7r$ (45), c' = correction for open end (if pipe has a flange $c' = 0.82r$ (36), if no flange $c' = 0.6r$ (45), observed value for thin brass tube of $r = 5.3$ cm is $c' = 0.576r$ (6)), v = velocity of sound in fluid filling the pipe = $\sqrt{\gamma p/\rho} = v_0\sqrt{1 + \alpha t + \beta t^2}$, γ = ratio of specific heats; for air, $v_0 = 330.6$ m/sec, $\alpha = 0.00371$, $\beta = -0.126 \times 10^{-6}$, for other fluids, *see* p. 461. The pitch of the sound actually emitted increases with the blowing pressure; for a pipe of natural pitch 255 v.p.s., the observed pitch was $255 + \delta$, where δ varied as follows (46):

p	1.9	2.08	2.2	2.69	3.35
δ	−0.5	+0.1	+1.5	+2.1	+4.2

p	3.88	4.72	5.74	6.92	10.7 cm H_2O
δ	+5.6	+7.1	+8.4	+9.3	+11 v.p.s.

The intensity (I) also increases with the blowing pressure (37):

p	20	24.8	30.8	35.8	39.0	cm H_2O
I	4	9	18	26	35	Arbitrary units

16. *Tonvariator* (53) is a Helmholtz resonator blown by air-blast. Its pitch can be varied continuously over about an octave; its tone is practically pure, the overtones being very high and weak (25, 47). The intensity (I) increases linearly with the blowing pressure (p cm of H_2O), at least within the range $10 < p < 39.5$, being given by $I = 0.67p - 4.7$, unit of I being arbitrary (37).

17. *Galton's pipe* gives tones varying from about 3 500 to 50 000 v.p.s., depending upon its length (l) and the width (w) of its mouth (17):

l	22.4	7.18	4.21	2.7	1.8
w	2.3	1.6	0.9	0.9	0.9
$N/1000$	3.48	10.0	15.0	20.0	25.0

l	1.26	0.82	0.47	0.27 mm
w	0.9	0.9	0.9	0.9 mm
$N/1000$	30.0	35.0	40.0	45.0 v.p.s.

18. *Singing tube* (35) consists of an outer glass (pyrex) tube closed at one end, and a shorter inner tube open at both ends and at one end sealed to the outer tube at such a place that its other end is near the closed end of the outer tube. When the relative dimensions of the tubes are suitably adjusted, a strong, pure tone is emitted when the closed end of the tube is heated. The pitch depends upon the difference in temperature of the two ends of the tube. For a certain tube the following data were obtained (34):

t_c	1	204	355	448	524	°C
t_o	−181	−88	−16	+26	+57	°C
$t_c - t_o$	182	292	371	422	+467	°C
N	213	300	378	425	450	v.p.s.

19. *Thermophone* (2, 57).—When a very thin metallic strip immersed in a fluid is heated by an alternating electric current, the periodic expansion and contraction of the adjacent film of fluid give rise to vibrations in the fluid. The intensity of the sound is low, and is indefinite unless the fluid is confined in an enclosure of which the dimensions are all small as compared with the wavelength of the vibrations. If the heating current has a pure sine-wave form, the emitted sound is a pure tone of twice the frequency of the current. (*See* Fig. 5.)

20. *Siren.*—In a "pure tone" siren, the overtones are weak (42). (*See* Fig. 6.)

21. *Diaphone* (32) is a modified siren. It consists of a cylinder fitted with a piston which is oscillated through a small amplitude by compressed air, and which intermittently interrupts an air-blast. It emits a powerful tone. It may emit 1.76 kw (2.36 h.p.) of acoustic energy with an over-all efficiency of 6 to 8% and be heard for miles.

22. *Explosives* (23, 24, 52).—The detonation of bombs containing from 225 to 900 g (0.5 to 2 lb.) of T.N.T. (2, 4, 6-trinitrotoluene, $C_7H_5N_3O_6$) has been used as an under-water source of sound. The sound from a 500 g bomb detonated at 8 to 10 m below the surface has been detected under water at distances of 15 to 18 km (52).

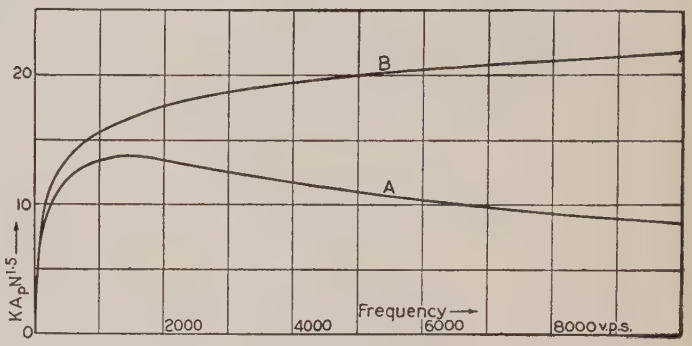

FIG. 5.—Thermophone: Relation between frequency (N) and amplitude (A_p) of oscillation of pressure (57).

In each case mean temperature of strip = 335°K, of air in enclosure = 300°K. For A, strip was a Wollaston wire 1 cm long, $2r = 0.003$ mm; volume of enclosure = 1 cm³; for B, strip was gold foil, area = 5.5 cm², thickness = $0.079\mu = 0.79 \times 10^{-5}$ cm; volume of enclosure = 14 cm³. K is a constant.

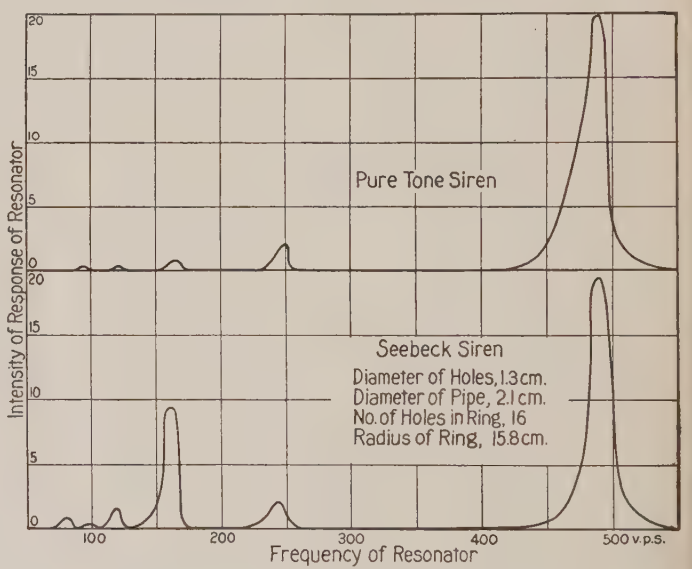

FIG. 6.—Sirens: Comparison of "Pure tone" and Seebeck sirens (42).

Notes analyzed by means of resonators. Arbitrary unit of intensity.

DEVICES FOR STABILIZING THE FREQUENCY OF OSCILLATION OF CIRCUITS CONTAINING ELECTRON TUBES

The frequency of an oscillating electron tube and circuit may be stabilized by the use of a piezoelectric resonator (*see* No. 12 above). Variations with resonator are only about 3% of those without (8).

By the use of 2 electron tubes and coupling by tuned impedances, the frequency of oscillation of the circuit may be made quite independent of changes in plate voltage and in filament current.

In one case a change of 50 % in plate voltage produced but 0.1 %, and of 43 % in filament current produced but 0.3 %, change in the frequency (20).

By the use of a tuning fork (14, 29), the frequency can be maintained constant and equal to that defined by the fork to within 1 part in 100 000. Changing tubes produced a maximum effect of 1 in 100 000; there was no change as the tubes aged and no change as the filament current was reduced, provided the current was not less than 80 % of its normal value. As the plate voltage was increased the frequency increased by 0.0002 % per volt of change.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Aigner, *Unterwasserschalltechnik.* Berlin, Krayn, 1922. (2) Arnold and Crandall, *2*, **10**: 22; 17. (3) Barton, *A textbook on sound.* London, Macmillan, 1914. (4) Barton, *in B2*, **IV**. (5) Berger, *Die Schalltechnik.* Braunschweig, Vieweg, 1926. (6) Blaikley, *3*, **7**: 339; 79. (7) Cady, *2*, **21**: 371; 23. (8) Cady, *48*, **10**: 475; 25. (9) Chwolson, *Traité de physique.* **I**: No. 4. Paris, Hermann, 1908.
(10) Crandall, *Theory of vibrating systems and sound.* New York, Van Nostrand, 1926. (11) Dadourian, *2*, **13**: 337; 19. (12) Davis, *65*, **41**: 691; 06. (13) Discussion on Loud-Speakers, *67*, **36**: 211; 24. (14) Eccles and Jordan, *121*, **82**: 704; 19. (15) Eckhardt, *143*, **194**: 49; 22. (16) Eckhardt, Karcher and Keiser, *48*, **6**: 949; 22. (17) Edelmann, *8*, **2**: 469; 00. (18) Geiger and Scheel, *B95*, **VII**. (19) Goldsmith and Minton, *529*, **12**: 423; 24.
(20) Gunn, *48*, **8**: 545; 24. (21) Hanna, *529*, **13**: 437; 25. (22) Hanna and Slepian, *129*, **43**: 393; 24. (23) Heck, Eckhardt and Keiser, *217*, No. **107**; 24. (24) Heck and Service, *217*, No. **108**; 24. (25) Helmholtz and Ellis, *On the sensations of tone.* London, Longmans, 1895. (26) Henrard, *L'onde électrique*, **4**: 120; 25. (27) Hewlett, *2*, **19**: 52; 22. (28) Hewlett, *48*, **6**: 1059; 22. (29) Horton, Ricker and Morrison, *129*, **42**: 730; 23.
(30) Kennelly, *Electrical vibration instruments.* New York, Macmillan, 1923. (31) Kimball, *2*, **25**: 116; 25. (32) King, *143*, **183**: 259; 17. (33) King, *143*, **187**: 611; 19. (34) Knipp, *2*, **17**: 532; 21. (35) Knipp, *58*, **120**: 362; 27. (36) Lamb, *The dynamical theory of sound.* London, Arnold and Co., 1925. (37) Love and Dawson, *2*, **14**: 49; 19. (38) Mallet and Dutton, *46*, **63**: 502; 25. (39) Melde, *in B76*, **II**: 293.
(40) Mercadier, *34*, **79**: 1001, 1069; 74. (41) Millet, *541*, **22**: 107; 14. (42) Milne and Fowler, *5*, **98**: 414; 21. (43) Pocock, *67*, **36**: 120; 24. (44) Rankine, *67*, **36**: 115; 24. (45) Rayleigh, *3*, **3**: 456; 77. (46) Rayleigh, *3*, **13**: 340; 82. (47) Rayleigh, *The theory of sound*, **II**. London, Macmillan, 1896. (48) Rice and Kellogg, *39*, **44**: 982, 1915; 25. (49) Richardson, *Sound.* New York, Longmans, 1927.
(50) Sawyer, *541*, **22**: 115; 14. (51) Schottky, *63*, **25**: 672; 24. (52) Stephenson, *2*, **21**: 181; 23. (53) Stern, *281*, **30**: 422; 02. *63*, **5**: 693; 04. (54) Stewart, *et al*, *337*, **4**: No. 23; 22. (55) Wegel, Bell Telephone Laboratories, New York, *0*. (56) Wente, *2*, **10**: 39; 17. (57) Wente, *2*, **19**: 333; 22. (58) Wente, *2*, **19**: 498; 22. (59) Winkelmann, *B76*, **II**.
(60) Wood and Ford, *J. Sci. Instruments*, **1**: 161; 24. (61) Wüllner, *8*, **4**: 321; 78.

DETECTION AND MEASUREMENT OF SOUND

E. A. Eckhardt

This bibliography covers all devices now available for quantitative measurements. For a recent discussion of such devices, *see* (39.1). Apparatus covering the range within which the human ear is sensitive (*see* p. 450) is very elaborate and compromises are generally required to meet a given situation.

1. Interferometric measurement of amplitude of changes in density (29, 35, 39).
2. Rayleigh disc: In free air (52); in simple resonator (12, 30); in double resonator (4, 38, 41).
3. Webster's phonometer (21, 42, 43).
4. Wien's vibration manometer (47, 51).
5. Torsion balance for measuring pondermotive force (2, 31, 51), theory (31).
6. Miller's phonodeik (23).
7. Ballistic phonometer (3).
8. Acoustic valves (28).
9. Magnetophones (20, 27, 34).
10. Contact microphones (10, 27).
11. Thermo-microphones (8, 9, 15, 16, 17, 24, 25, 33, 40).
12. Condenser microphones (5, 45, 46).
13. Resonators (13, 25, 26, 32, 40).
14. Horns (7, 11, 14, 18, 26, 36, 37, 43, 44).
15. Geophones (1, 22).
16. Hydrophones (6, 19, 48, 49, 50).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ackley and Ralph, *313*, No. **2639**; 24. (2) Altberg, *8*, **11**: 405; 03. (3) Banerji, *3*, **32**: 96; 16. (4) Boys, *in B2*, **3**: 723; 23. (5) Crandall, *2*, **11**: 449; 18. (6) Drysdale, *46*, **58**: 572; 20. (7) Foley, *2*, **20**: 505; 22. (8) Friese and Waetzmann, *96*, **29**: 110; 24. (9) Friese and Waetzmann, *8*, **76**: 39; 25.
(10) Gáti, *Elektrotech. Maschinenbau*, **36**: 527; 18. (11) Goldsmith and Minton, *529*, **12**: 423; 24. (12) Grimsehl, *8*, **34**: 1028; 88. (13) Hahnemann and Hecht, *63*, **22**: 353; 21. (14) Hanna and Slepian, *39*, **43**: 250, 1191; 24. (15) Heindlhofer, *8*, **37**: 247; 12. (16) Heindlhofer, *8*, **45**: 259; 14. (17) von Hippel, *8*, **75**: 521; 24. (18) Hoersch, *2*, **25**: 218, 225; 25. (19) Hopwood, *58*, **103**: 467; 19.
(20) Karcher, *31*, No. **473**; 23. (21) King, *62*, **218**: 211; 19. (22) Leighton, *30*, No. **277**; 22. (23) Miller, *Science of musical sounds.* New York, Macmillan, 1916. (24) Neuscheler, *8*, **34**: 131; 11. (25) Paris, *5*, **101**: 391; 22. (26) Paris, *3*, **48**: 769; 24. (27) Pierce, *65*, **43**: 375; 08. (28) Raps, *8*, **36**: 273; 89. (29) Raps, *8*, **50**: 193; 93.
(30) Rayleigh, *3*, **14**: 186; 82. (31) Rayleigh, *3*, **3**: 338; 02. (32) Rayleigh, *3*, **36**: 231; 18. (33) Richards, *3*, **45**: 926; 23. (34) Sell, *Wiss. Veröffentlich. Siemens-Konzern*, **2**: 353; 22. (35) Sharpe, *506*, **27**: 205; 99. (36) Stewart, *2*, **16**: 313; 20. (37) Stewart, *2*, **25**: 230; 25. (38) Stewart and Stiles, *2*, **1**: 309; 13. (39) Töpler and Boltzmann, *8*, **141**: 321; 70. (39.1) Trendelenburg, *in* Geiger and Scheel's *Handbuch der Physik*, **8**: 572; 27.
(40) Tucker and Paris, *62*, **221**: 389; 21. (41) Watson, *Acoustics of buildings.* New York, Wiley, 1923. (42) Webster, *197*, **5**: 173; 19. (43) Webster, *197*, **5**: 275; 19. (44) Webster, *197*, **6**: 316; 20. (45) Wente, *2*, **10**: 39; 17. (46) Wente, *2*, **19**: 498; 22. (47) Wien, *8*, **36**: 834; 89. (48) Wilson, *2*, **15**: 178; 20. (49) Wood and Young, *5*, **100**: 252; 21.
(50) Wood and Young, *5*, **100**: 261; 21. (51) Zernov, *8*, **21**: 131; 06. (52) Zernov, *8*, **26**: 79; 08.

TRANSMISSION, REFLECTION, REVERBERATION AND ABSORPTION OF SOUND

P. E. Sabine

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SYMBOLS AND DEFINITIONS

A	Amplitude of displacement of element of the medium.
a	Absorbing power.
E	Bulk modulus, modulus of volume elasticity.
I	Intensity of the sound.
l	Length of a tube, or thickness of a septum.
N	Frequency, pitch, number of complete vibrations per unit of time.
P	Acoustic power.
R	Radius.
s	Area.
T	Duration of audible reverberation.
t	Time.
V	Volume of room or other enclosure.
v	Velocity of sound in medium considered.
v.p.s.	Vibrations per second.
α	Coefficient of absorption.
δ	Damping coefficient, coefficient of attenuation.
λ	Wave-length.
μ	Acoustic resistivity.
ρ	Density.
σ	Mass of septum per unit of area.

Absorbing Power.—As the result of the absorption of sound by a surface of area s, the intensity of the sound in an enclosure dies away exponentially after its emission ceases; $I_t = I_0 e^{-\alpha s v t/4V}$, where t is the time that has elapsed since I had the value I_0, the source having ceased to emit sound prior to the beginning of the interval t, and v is the velocity of sound in the medium which fills the volume V. The absorbing power of the surface is αs, and α is the coefficient of absorption. If the boundaries (walls, fittings, and occupants) consist of several types of surfaces, the total absorbing power is $a = \alpha_1 s_1 + \alpha_2 s_2 + \cdots$; it is of the dimensions of an area.

Acoustic power is the amount of acoustic energy that is emitted per unit of time.

Acoustic resistivity of a medium is $\mu = \sqrt{E\rho}$. It is the amount by which the r.m.s.[1] pressure in a plane wave must exceed the static pressure if the r.m.s.[1] velocity of the medium is to be unity.

Coefficient of Absorption.—*See* Absorbing power.

[1] r.m.s. = square root of the mean square.

Coefficient of Attenuation.—As a sound travels along a tube, the intensity decreases exponentially; $I_x = I_0 e^{-\delta x}$; δ is coefficient of attenuation.

Intensity (I) of a sound is used in this section to denote the amount of acoustic energy per unit volume of the medium. For a single beam of advancing sound, Iv is the acoustic energy transmitted per unit of time through a unit of area perpendicular to the direction of propagation.

Transmittivity of an interface or septum = (transmitted energy) ÷ (incident energy).

Reflectivity of a surface = (reflected energy) ÷ (incident energy).

Table 1.—Transmission of Sound through Tubes, Horns and Wave-filters

Amplification by horns: theoretical (**1, 2, 7, 8, 14, 17, 23, 37**); experimental (**3, 4, 12, 14, 15, 16, 18, 20, 21, 22, 31, 38, 39**).

Wave-filters are conduits with side openings and, in certain types, associated branches and air-chambers; sounds in predetermined ranges of frequencies cannot pass through them. Theory and experiments (**32**).

For cylindrical tubes, radii R_1 and R_2 ($R_2 = r_2 R_1$), connected by a cone of length l, sound proceeding from tube 1 to tube 2,

$$\frac{A_2 R_2^2}{A_1 R_1^2} = \frac{1}{\left[1 + \frac{(r_2-1)^2}{r_2}\cdot\frac{(1-\cos\eta)}{\eta^2}\right]^2 + \left[\frac{(r_2-1)^2}{r_2}\cdot\frac{(\eta-\sin\eta)}{\eta^2}\right]^2}$$

where $\eta = \frac{4\pi l}{\lambda}$ (**5**).

For tube of constant R, $I_x = I_0 e^{-\delta x}$; tabular values are δ (**11**). Unit of R = 1 cm = 0.394 in.; of l = 1 m = 3.28 ft.; of N = 1 v.p.s.; of δ = 0.01 m^{-1} = 0.00305 $ft.^{-1}$.

$2R$	N	254	1040	2285	3280	254	1040	2285	3250
	Material	Straight tube				l = 3.04; 90° bend			
2.70	Brass	9.8		16.7	15.7				
2.70	Iron	12.1	13.4	18.7	20.0				
2.54	Fiber	14.8	15.1	25.2	30.2				
4.92	Brass	6.9	8.2	12.1	11.8	6.9	8.9	8.9	14.4
4.92	Fiber	8.9	13.5	14.1	15.1				
7.30	Brass	5.6	6.2	8.9	8.2	6.2	8.2	9.8	10.2
9.84	Brass		4.9	6.6	5.6	4.1	3.1	10.3	7.2

TABLE 2.—ACOUSTIC RESISTIVITY AND TRANSMISSION OF PLANE WAVES FROM MEDIUM TO MEDIUM (5)

The external media are assumed to have a thickness that is great as compared with λ; the media are indicated by subscripts, 1, 2, 3, . . . , in the order in which they are entered by the wave, A_1, A_1r = displacement amplitude of incident, of reflected, wave in medium 1.

Two media, plane boundary, normal incidence. $A_1 - A_1r = A_2$; $(A_1 + A_1r)\mu_1 = A_2\mu_2$; $(A_1 + A_1r)/(A_1 - A_1r) = \mu_2/\mu_1$. Write m_2 for μ_2/μ_1; *i.e.*, $\mu_2 = m_2\mu_1$. Then for the interface, the transmittivity is $A_2^2\mu_2/A_1^2\mu_1 = 4m_2/(m_2 + 1)^2$; the reflectivity is $(m_2 - 1)^2/(m_2 + 1)^2$.

Three media, plane parallel boundaries, normal incidence. Let $m_2 = \mu_2/\mu_1$, $m_3 = \mu_3/\mu_2$, and l_2 and λ_2 = thickness of medium 2 and wave-length in it; then the transmittivity of the septum is

$$\frac{4m_2m_3}{(m_2m_3 + 1)^2}\left\{\frac{1}{1 - \left[\frac{(m_2^2 - 1)(m_3^2 - 1)}{(m_2m_3 + 1)^2}\sin^2\frac{2\pi l_2}{\lambda_2}\right]}\right\}$$

Acoustic resistivity $(\mu) = \sqrt{E\rho}$; velocity $(v) = \sqrt{E/\rho}$. Unit of E = 1 kg wt./mm^2 = 1422 lb. wt./in.^{2}; of ρ = 1 g/cm^3 = 62.4 lb./ft.^{3}; of v = 1 m/sec = 3.28 ft./sec; of $\mu = 10^4$g cm^{-2} sec^{-1} = 2.05 × 10^4 lb. ft.$^{-2}$ sec.$^{-1}$.

Medium	E	ρ	v*	μ*
Steel	20 000	7.8	5 010	391
Cast iron	9 500	7.0	3 650	255
Brass	6 500	8.4	2 750	232
Bronze	3 200	8.8	1 890	166
Lead	600	11.4	718	81.9
Wood: Teak	1 600	0.86	4 270	37
Fir	900	0.45	4 430	20
Beech	600	0.80	2 710	22
Water	200	1.0	1 400	14
Rubber	<1	*ca.* 1	<100	<1
Air	0.014	0.0013	325	0.004

* The numbers in this column have been slightly changed in order to make them accord with the tabulated values of E and ρ.

TABLE 3.—TRANSMISSION OF SOUND THROUGH SEPTA BOUNDED BY AIR

Quilts.—Soft, flexible, porous, highly absorbent septa (25). $\text{Log}_{10}(I_1/I_3) = \beta + \gamma l_2$, where l_2 = thickness of the septum and I_3 is intensity after passage through the septum. Unit of ρ = 1 g/cm^3 = 62.4 lb./ft.^{3}; of N = 1 v.p.s.; of β = 0.01; of γ = 0.01 cm^{-1} = 0.305 ft.$^{-1}$.

Material of septum	ρ	N	128		256		512		1024		2048		4096	
		Covering	β	γ	β	γ	β	γ	β	γ	β	γ	β	γ
Hair, loosely felted	0.14	None	38	5	25	8	35	10	35	15	26	17	48	17
Plant fiber board, coarse	0.24	None	77	25	77	20	68	29	105	41	10	70	22	80
Seaweed, quilted	0.11	Light paper	85	14	67	14	58	22	33	34	35	35	30	52
Plant fiber, soft, quilted	0.14	Heavy paper	71	17	56	14	45	23	45	55	50	108	100	123
Hair and asbestos fiber	0.40	Heavy paper	122	22	130	24	122	43	110	65				
Hair and asbestos fiber	0.55	Paper + burlap	60	36	96	34	87	63	56	100				

Wood, Glass, Steel (24).—Sound transmitted by forced vibrations of the septum: resonance may cause a large variation in transmission for a small variation in pitch. Tabulated values are averages for the 6 values of N of the preceding section. Each complete septum was 2.1 m by 0.79 m (= 6.9 ft. by 2.59 ft.); l = thickness of septum. Unit of l = 1 cm = 0.394 in.

Material	Remarks	l	I_1/I_3
Plate glass	1 pane	0.63	200
Plate glass	4 panes each, 38 by 99 cm	0.63	282
Plate glass	4 panes each, 38 by 99 cm	0.47	190
Plate glass	Small, leaded panes	0.47	302
Window glass	12 panes, each 25.4 by 48 cm	0.32	140
Steel door		0.63	1020
Wooden door	Panelled, birch veneer		74
Oak door	Solid, well seasoned	4.45	140
Oak door	Solid, damp	4.45	231

Masonry (27).—Tabulated values are averages for 20 tones covering the range N = 128 to 4096 v.p.s.; each septum was 1.88 m by 2.34 m (= 6.17 ft. by 7.68 ft.); $I_1/I_3 = K\sigma^{2.5}$, approximately, where K = 0.0112 m^{5}kg$^{-2.5}$ = 0.590 ft.^{5} lb.$^{-2.5}$; l_t, l_p, l = thickness of tile, of plaster, of complete septum. Unit of l_t, l_p, l = 1 cm = 0.394 in.; of σ = 1 kg/m^2 = 0.205 lb. ft.^{2}

Material	Remarks	l_t	l_p	l	σ	I_1/I_3	$K\sigma^{2.5}$
Gypsum tile	Solid	5.08		5.08	50.8	230	206
Gypsum tile	Hollow	7.62		7.62	54.3	260	243
Plaster	Solid, metal lath		3.81	3.81	68.0	340	427
Gypsum tile	Solid	7.62		7.62	69.5	468	451
Clay tile	Hollow	10.16		10.16	83.2	677	708
Gypsum tile	Solid, plastered	5.08	3.16	8.24	104.8	1180	1375
Gypsum tile	Solid, plastered	7.62	3.16	10.78	124.2	1910	1923
Clay tile	Hollow, plastered	10.16	3.16	13.32	141.0	2500	2640
Plaster	Solid, metal lath		8.9	8.9	159.0	4000	3570
Plaster	Solid, metal lath		11.75	11.75	204.0	6600	6660

TABLE 4.—COEFFICIENT OF ACOUSTIC ABSORPTION BY BOUNDARIES

If I_0 is the intensity of sound in an enclosure, of volume V, at some instant after the production of the sound has ceased, the intensity at a later time is $I_t = I_0e^{-avt/4V}$, where $a = \alpha_1s_1 + \alpha_2s_2 + \cdots$; s_1 = area of the boundary for which the coefficient of absorption is α_1; α_{512} = value of α for N = 512 v.p.s.; α_{av} = average value of α for range N = 128 to 4096 v.p.s. For data for special commercial sound-absorbent materials, *see* (36).

Masonry.—l_m, l_c = thickness of material, of coating. Unit of l_m, l_c = 1 cm = 0.394 in.; of α_{512}, α_{av} = 0.01.

Finish	Material	l_m	l_c	α_{512}	α_{av}	Lit.
Unpainted	Brick	45		3.1	4.0	(26)
Painted	Brick	45		1.7	1.9	(26)
Smooth	Brick + gypsum plaster	45	1.5	1.2	1.5	(29)
Smooth	Clay tile + gypsum plaster	10		2.2	3.4	(29)
Smooth	Gypsum block + gypsum plaster	7.6		4.4	3.6	(29)
Smooth	Lime plaster, wood lath and studding			1.8	2.9	(26)
Smooth	Clay tile + gypsum plaster	10		2.0	2.8	(26)
Rough	Clay tile + gypsum plaster	10		4.9	4.4	(29)
Rough	Gypsum plaster, metal lath	6.3		4.7	3.6	(29)
Rough	Gypsum plaster, metal lath *	11.4		4.7	3.0	(29)
Rough	Lime plaster, wood lath and studding	11.4		3.4	3.0	(26)

* Wood studding.

Furnishings and Wall Coverings.—α determined by method of reverberation, unless another is indicated; "draped" = draped back one-fourth; l = thickness of covering, σ = mass of covering per unit area. 1 cm = 0.394 in.; 1 g/m^2 = 0.00184 lb./yd.^{2} = 0.000205 lb./ft.^{2}; unit of α = 0.01.

Material	Remarks	α_{512}	Lit.
Audience	Closely seated	96	(26)
Cork	l = 2.54 cm	12	(26)
Cork	l = 3.8 cm	32*	(34)

TABLE 4.—(*Continued*)

Material	Remarks	α_{512}	Lit.
Carpet	l = 0.8 cm	20	(26)
Carpet	Brussels	23*	(34)
Cheesecloth	σ = 48 g/m²	1.9	(26)
Chenille		23	(26)
Coco matting		17	(30)
Cotton draperies	Straight, σ = 330 g/m²	9	(29)
Cotton draperies	Draped, σ = 330 g/m²	29	(29)
Velour draperies	Straight, σ = 580 g/m²	10	(29)
Velour draperies	Draped, σ = 580 g/m²	37	(29)
Rugs	Oriental	29	(26)
Rugs	Oriental	26*	(34)
Linoleum		12	(26)
Felt	Asbestos, l = 1.0 cm	35	(26)
Felt	Asbestos, l = 1.9 cm	26*	(34)
Felt	Asbestos and hair	38	(26)
Felt, loose	Hair, l = 2.54 cm	52	(26)
Felt, loose	Hair, l = 2.54 cm	49	(29)
Felt, loose	Hair, l = 2.54 cm	51*	(34)
Felt, wood fiber	l = 2.54 cm, σ = 1400 g/m²	57	(29)
Fiber board	Sugar cane, l = 1.1 cm	20	(29)
Fiber board	Flax, l = 1.43 cm	28	(29)
Fiber board	Sugar cane, l = 1.27 cm	31	(35)
Fiber board	Wood, l = 1.27 cm	31	(35)
Glass		3	(26)
Wood sheathing	Pine, l = 2 cm	10	(26)
Cushions	α_{512} varies from 54 to 76	60	(26)

* Flue method.

TABLE 5.—ABSORBING POWER OF OBJECTS

Absorbing power (a) of an object = αs (*cf.* Table 4). Unit of a = 0.01 m² = 0.108 ft.²

Object	Remarks	a	Lit.
Audience	Per person	44	(26)
Chairs	Ash	1	(26)
Chairs	Wood, veneered	3	(29)
Church pews	Wood, per sitting	2	(35)
Pew cushions	Per sitting	13.5 to 19	(26)
Opera chairs	Seats upholstered	9 to 23	(35)
Opera chairs	Seats and backs upholstered	14 to 19	(29)

TABLE 6.—REVERBERATION IN ROOMS

Duration (T) of audible reverberation in a room of volume V and absorbing power a is $T = \frac{4V}{av}\log_e\frac{I_0}{i} = \frac{9.2V}{av}\log_{10}\frac{I_0}{i}$, where I_0 = average intensity of the sound at the instant its production ceased $= \frac{4P}{av}(1 - e^{-avt/4V})$, where t = the time the sound has been continuously produced; i = minimum audible intensity. Assume v = 342 m sec^{-1} (= 1122 ft. sec^{-1}) and t is so great that $I_0 = 4P/av$, and put T_0 = value of T when $I_0/i = 10^6$; T_{10} = value of T when $P/i = 10^{10}$ m³ sec^{-1} (= 35.3 × 10^{10} ft.³ sec^{-1}). Then if units are 1 m and 1 sec, $T_0 = 0.161V/a$, $T_{10} = 0.0269\frac{V}{a}(8.07 - \log_{10} a)$, and if units are 1 ft. and 1 sec, $T_0 = 0.049\frac{V}{a}$, and $T_{10} = 0.0082\frac{V}{a}(9.10 - \log_{10} a)$.

For each of the 11 rooms considered below, T is considered satisfactory for the purpose indicated. Values of T_0 and T_{10} are computed from V and the known values of α for the surfaces and furnishings, assuming N = 512 v.p.s. and that the audience fills the room to its capacity. Key = key number of room. Unit of V = 1 m³ = 35.3 ft.³; of T_0 and T_{10} = 1 sec.

Key	Purpose	V	Seats	T_0	T_{10}	Lit.
1	Piano	74 to 210		0.95 to 1.10	1.07 to 1.19	(26)
2	Intimate drama	1 700	300	1.20	1.14	(26)
3	Drama	5 900	1 670	1.51	1.23	(35)
4	Orchestra	11 500	1 600	2.35	2.02	(26)
5	Music, speech	12 200		1.70	1.41	(33)
6	Orchestra	18 400	2 600	2.33	1.92	(26)
7	Opera	14 200	2 350	1.51	1.23	(29)
8	Orchestra	20 600	2 300	2.40	1.96	(29)
9	Orchestra	22 400	3 340	2.08	1.66	(35)
10	Orchestra, speech	22 600	5 000	1.70	1.33	(33)
11	Music, speech	26 200	3 640	1.90	1.48	(29)

KEY NUMBERS AND LOCATIONS OF ROOMS STUDIED

Key	Name and location
1	New England Conservatory, Boston (5 small rooms)
2	Little Theater, New York, N. Y.
3	Apollo Theater, Chicago, Ill.
4	Gewandthaus, Leipzig, Germany
5	Academy of Music Opera House, Brooklyn, N. Y.
6	Symphony Hall, Boston, Mass.
7	Opera House, Boston, Mass.
8	Masonic Auditorium, Cleveland, Ohio
9	Eastman Theater, Rochester, N. Y.
10	Hill Memorial, Ann Arbor, Mich.
11	Auditorium Theater, Chicago, Ill.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Barton, *3*, **15**: 69; 08. (2) Bernouilli, *151*, **1762**: 431. (3) Blaikley, *3*, **6**: 119; 78. (4) Boutet, *6*, **21**: 150; 70. (5) Brillé, *384*, **75**: 171; 19. (6) Chrisler, *31A*, **22**: 227; 27. (7) Crandall, *Theory of vibrating systems and sound*. New York, Van Nostrand, 1926. (8) Duhamel, *408*, **14**: 49; 49. (9) Eckhardt, *143*, **195**: 799; 23.
(10) Eckhardt and Chrisler, *31A*, **21**: 37; 26. (11) Eckhardt, Quayle, Evans and Buckingham, *32*, No. **333**; 26. (12) Foley, *2*, **20**: 505; 22. (13) Franklin, *2*, **16**: 372; 03. (14) Goldsmith and Minton, *529*, **12**: 423; 24. (15) Gripon, *34*, **68**: 909; 69. (16) Hanna and Slepian, *39*, **43**: 250; 24. (17) Hoersch, *2*, **25**: 218; 25. (18) Hoppe, *63*, **13**: 1051; 12. (19) Jäger, *75*, **120 IIa**: 613; 11.
(20) Mahillon, *2*, **2**: 193; 01. (21) Masson, *6*, **48**: 5; 56. (22) Neyreneuf, *6*, **16**: 562; 99. (23) Rayleigh, *The theory of sound*, II. London, Macmillan, 1896. (24) Sabine, *530*, **118**: 102; 20. (25) Sabine, *530*, **120**: 215, 266; 21. (26) Sabine, *Collected papers on acoustics*. Cambridge, Mass., Harvard Univ. Press, 1922. (27) Sabine, *530*, **124**: 23; 23. (28) Sabine, *530*, **125**: 579; 24. (29) Sabine, *0*.
(30) Stewart, *116*, **17**: 295; 03. (31) Stewart, *2*, **16**: 313; 20. (32) Stewart, *2*, **17**: 382; 21. **19**: 401; 22. **20**: 528; 22. **25**: 90; 25. (33) Tallant, *The Brickbuilder*, **19**: 243; 10. (34) Taylor, *2*, **2**: 270; 13. (35) Watson, *Acoustics of buildings*. New York, Wiley, 1923. (36) Watson, *86*, No. **172**; 27. (37) Webster, *197*, **5**: 275; 19. (38) Webster, *197*, **6**: 316; 20. (39) Zamminer, *8*, **7**: 173; 56.

VELOCITY OF SOUND

ARTHUR L. FOLEY

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As the determination of the velocity of sound is beset by many difficulties, the values obtained by different observers under nominally identical conditions are frequently quite different. Hence, it has seemed best to give either the individual observations, if few, or the simple average of all, if many (occasionally excluding a few that are markedly discordant); and, when data corresponding to each of a series of values of a single variable are available, to give, if possible, the coefficients of a simple empirical equation that represents the series within the estimated experimental error. Such an equation should not be used beyond the indicated limits. The averages and coefficients have been determined for these tables; the literature references indicate merely the sources of the data upon which they rest. Wherever given, the deviations from the equations refer to the deviations of the values derived by the authors, not necessarily of the individual determinations.

SYMBOLS

t Temperature, °C.

T, T_0 Absolute temperature, absolute temperature of 0°C.

V Velocity of sound in an unlimited volume of the medium, except in Table 7 where it is the observed velocity in the confined gas. Subscripts (*e.g.*, V_t) indicate the temperature, or the temperature and pressure, to which V refers.

RELATION OF VELOCITY OF SOUND TO VARIOUS FACTORS

Pitch.—For frequencies up to 800 000 per sec, the velocity in free air and in free illuminating gas has been found to be independent of the pitch (22, 58). For air and CO_2, *see* (71). When a gas is confined in a tube, the velocity is less than in the free gas, but approaches that as the frequency is increased; *see* Table 7. In liquids also, the velocity is independent of the pitch unless the viscosity is very great and the frequency is very high; in going from 43 000 to 600 000 per sec, the velocity in water decreases only 5% (8). In glass rods, the velocity of transverse waves increases with the frequency and with the diameter; an increase from 400 m/sec to 2 400 m/sec has been observed when the frequency was increased from 285 000 to 455 000 per sec (111).

Intensity.—Even at ordinary intensities, the velocity is only approximately independent of the intensity, and at great intensities it is far from such independence, the velocity increasing with the intensity (9, 28, 32, 50, 61, 62, 72, 73, 83, 96, 97, 100, 102, 109). The effect of the motion of the medium (*q.v.*) must be considered. Velocities ranging from 331 to 1270 m/sec in air (32, 72, 100), and from 1400 to 2013 m/sec in water (96) have been observed.

Medium.—Unless the intensity is great, the velocity of sound with reference to the medium is quite approximately given by the equation $V^2 = E/d$, where E is the adiabatic volume elasticity, and d is the density of the medium. In general, both E and d vary with the temperature, pressure, and composition of the medium. For an ideal gas, $E = \gamma p$, and $V_t = V_0 T/T_0$ is independent of the pressure; γ = ratio of the specific heats. For many actual gases an equation of the form $V^2_{t,p} = V^2_{0,p}(1 + at + bt^2)$ represents the observations within their experimental error; a will usually differ from $1/T_0$. Irons (47) concludes that the best general equation is $V = a + bT^n$, where n is near 0.5 and varies with the complexity of the molecule.

Velocity of Medium.—When the medium is streaming with reference to the observer, the apparent velocity of the sound is the sum of the normal velocity and that component of the mass velocity of the medium which is in the direction of the line joining the source and the observer. The wave-front of the sound wave from a gun is a circle with a moving center (67); if the distance measured along the axis of the gun from the muzzle to the wave-front is x, then $x = V\tau + a(1 - e^{-b\tau})$, where V is the normal velocity, and τ is the time since the initiation of the wave. The apparent velocity is $dx/d\tau = V + abe^{-b\tau}$. For a 10-inch gun firing a service charge, a = 22 m, and b = 27 sec^{-1} (67); *see also* (48).

Velocity of Source.—Giving the source a velocity of 85.5 m/sec with reference to the medium and observer, relatively at rest, produces no change in the velocity of the sound (1).

Radiation.—Under the action of X-rays an increase of 5% in the velocity in O_2 and N_2, and a greater increase in H_2 have been observed (55). The action of ultra-violet light on O_2 forms ozone and decreases the velocity. Radiation from Ra produces no change. Velocity in argon is unaffected by radiation (92). It has been suggested that the effect upon the velocity arises, in general, from a change in the ratio of the specific heats (20).

Topography.—The apparent velocity in free air is affected by the local topography and altitude (10, 59, 85).

TABLE 1.—VELOCITY OF SOUND IN FREE AIR

The following data refer to dry air. The presence of water vapor increases the velocity. If e = pressure of water vapor present in air at barometric pressure p, then

$$V_d = V_h\sqrt{1 - \frac{e}{p}\left(\frac{\gamma_w}{\gamma_a} - \frac{5}{8}\right)},$$

where V_d and V_h = velocity in dry and in humid air of the same temperature, and γ_a and γ_w = ratio of specific heats of air and of water (88). Observed values (59) of V_h at 75 % of saturation and over range −14 to +27°C are significantly greater than those computed by means of this equation, the value at 21.85° being 353.0 m/sec while the values computed for 50 % and 100 % are only 345.5 and 346.2, V_d being taken as 344.7, which corresponds to $V_0 = 331.7$. Unit of V = 1 m/sec; of p = 1 atm.; temperature = t, °C.

Velocity (V_0) at 0°C, and 1 Atm.

It has been noticed (33) that, from 1738 to 1919, there seems to be a progressive decrease, totaling about 0.3 %, in the recorded values of V_0, suggesting a slight change in the constitution of the atmosphere. This decrease has not been considered in taking the following averages. In the table are given (*a*) the unweighted averages of the recorded values grouped roughly according to method used; (*b*) the weighted average of all values obtained prior to 1902 (74); and (*c*) the average of the 1902 average and the best values obtained since then (33).

Method	Range	V_0	Lit.
Gun fire	330.7–332.4	331.4	(2, 3, 10, 12, 30, 34, 67, 68, 72, 90)
Pipes and tubes	330.0–331.9*	331.1	(6, 22, 23, 26, 57, 72, 80, 88, 101, 102, 105)
Other methods	331.3–332.1	331.6	(39, 40, 59, 94, 95)
Weighted mean prior to 1902		331.78	(74)
Weighted mean to 1927		331.45	(33)

* Omitting 328.6 (23).

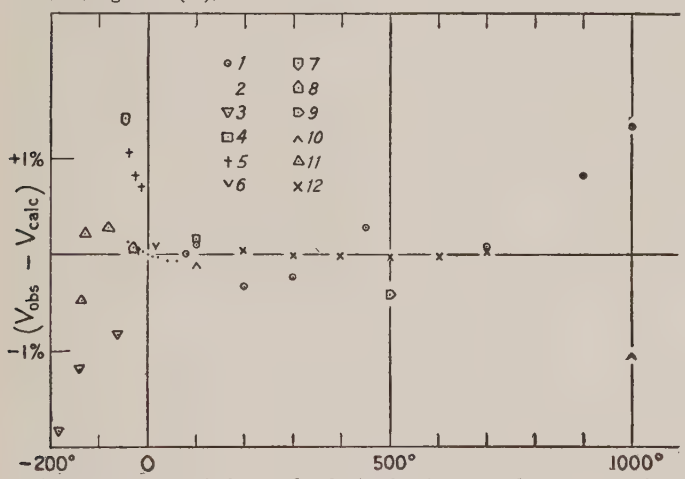

FIG. 1.—Excess of observed velocity in air above that calculated by means of the equation

$$V_t = 330.6\sqrt{1+0.003707t - 1.256t^2 10^{-7}}$$

1. Average of several observers.
2. Ciccone and Campanile (17).
3. Cook, and Witkowski and Cook (19, 107), values at −136° and −104°, 3.55 % and 3.42 % low, lie below the bottom of the figures.
4. Dixon, Campbell, and Parker (23).
5. Dulong (26).
6. Esclangon (30).
7. Greeley (38).
8. Grüneisen and Merkel (39).
9. Low (58).
10. Stevens (88).
11. Strecker (91).
12. Zoch (113).

Variation of V_t with Temperature

The recorded values between −181 and +1000° are represented by the equation $V_t = 330.6\sqrt{1 + 0.003707t - 1.256t^2 \times 10^{-7}} \times (1 + \delta)$, where δ has the values shown in Fig. 1; with two exceptions, the extreme range of δ is from −1.83 % at −181° to +1.42 % at −45.6°, and between 0 and 700° the range is from −0.43 to +0.29 %.

Variation of V_t with Pressure (52, 107); cf. (53, 89)

$\Delta \equiv (V_p - V_1) \div V_1$, temperature constant. Unit of p = 1 atm.; of Δ = 0.01

t	−140°	−103.5°	−79.3°	−78.5°	−35°	0°C	Lit.
p	Δ						
20	−16.8	− 3.1		−1.8	−0.3	− 0.1	(107)
25			−1.7			+ 0.8	(52)
40		− 5.8		−3.2	−0.3	+ 0.5	(107)
50			−1.8			+ 2.2	(52)
60				−2.5	0	+ 1.8	(107)
75			−0.2			+ 4.1	(52)
80					+1.3	+ 3.5	(107)
100						+ 6.0	(107)
100		+12.8				+ 6.4	(52)
125		+22.7				+ 9.5	(52)
150		+33.4				+13.2	(52)
175		+45.4				+17.3	(52)
200		+56.4				+19.0	(52)

TABLE 2.—VELOCITY OF SOUND IN GASES AND VAPORS: ONE TEMPERATURE

(For variation with temperature, *see* Table 3.) Temperature = t, °C; pressure = 1 atm.; Δ_a = average departure of observed velocities from the value tabulated; if no value given for Δ_a, there is but one acceptable determination. The symbols serve merely to identify the gases, and give no indication of their molecular states. Unit of V = 1 m/sec; of Δ_a = 1 % of V.

Gas	t	V_t	Δ_a	Lit.
Air	*See* Table 1			
A	0	307.8	0.2	(23, 45)
Br	0	135.0		(91)
Ca	850	652		(104)
Cl	0	205.8	0.2	(64, 91)
H	0	1261.7*	0.3	(21, 26, 39, 72, 75, 93)
He	0	971		(75)
Hg	330	187.0†		(54)
I	0	107.7†		(91)
K	850	652		(104)
N	0	337.7	0.1	(11, 23, 75, 79, 80)
O	0	316.2	0.3	(26, 75)
H_2O	0	401		(65)
HCl	0	295.2	0.4	(65, 80, 91)
HBr	0	199.8		(91)
HI	0	157.1		(91)
ICl	0	135.4		(91)
IBr	0	120.4		(91)
SO_2	0	209.2	0.1	(65, 80)
H_2S	0	289.3		(65)
NO	0	325		(65)
N_2O	0	260.5	1.3	(45, 64, 72, 80, 112)
NH_3	0	414.8	0.2	(65, 80, 112)
CO	0	337.4	0.1	(80, 112)
CO_2	0	259.3‡	0.6	(11, 23, 26, 45, 64, 65, 80, 112)
SiF_4	0	167.4		(65)

* Values 1238 (58), 1226 (80), and 1286.0 (113) have been ignored.
† At pressure of saturated vapor.
‡ Zoch (113) finds 281.9.

Formula	Name	t	V_t	Δ_a	Lit.
CCl_4	Carbon tetrachloride	77	150.2		(56)
CS_2	Carbon disulfide	0	195.0		(5)
$CHCl_3$	Chloroform	20	155		(5)
CH_2Cl_2	Methylene chloride	43	175.9		(36)

TABLE 2.—(*Continued*)

Formula	Name	t	V_t	Δ_a	Lit.
CH_4	Methane	0	430.5	0.3	(23, 65)
CH_4O	Methyl alcohol	67	341.2		(56)
C_2N_2	Cyanogen	0	229.5		(65)
C_2H_2	Acetylene	0	327.5	0.2	(45, 80)
C_2H_4	Ethylene	0	317.0	0.5	(26, 45, 65, 80, 112)
$C_2H_4O_2$	Acetic acid	136	209		(88)
C_2H_6	Ethane	0	303.0*		
C_2H_6O	Ethyl alcohol	0	230.6		(65)
C_3H_6O	Allyl alcohol	95	218.5		(36)
C_3H_6O	Propionaldehyde	50	258.3		(36)
C_3H_6O	Acetone	58	208.4		(36)
$C_3H_6O_2$	Propionic acid	146	232		(56)
$C_4H_8O_2$	Butyric acid	158	222.2		(56)
$C_4H_8O_2$	Isobutyric acid	150	208.4		(56)
$C_4H_8O_2$	Ethyl acetate	76	208.1		(56)
$C_4H_{10}O$	Ethyl ether	0	180.6	0.8	(5, 65)
$C_4H_{10}O$	Butyl alcohol	82	225.6		(56)
$C_5H_{10}O_2$	Valeric acid	169	218.4		(56)

TABLE 2.—(*Continued*)

Formula	Name	t	V_t	Δ_a	Lit.
C_5H_{12}	Pentane	43	191.5		(24)
$C_5H_{12}O$	Amyl alcohol	136	218.8		(56)
C_6H_6	Benzene	15	193		(5)
C_6H_{14}	Hexane	80	184.2		(24)
$C_8H_{16}O_2$	Isobutyl butyrate	157	184.3		(56)
$C_{10}H_{20}O_2$	Isoamyl valerate	166	157.2		(56)
	Benzine	90	200		(24)
	Coal gas	0	500†		(58, 113)
	Coal gas	13.6	453		(22)
	Gasoline	50	171.3		(36)

Mixed Gases (24), 20°C; volume %.

% H_2	% O_2	V	% H_2	% CO_2	% Air	V	% N_2	% CO	V
56.4	43.6	474.2	61.2	38.8		424.8	83.8	16.2	351.8
51.6	48.4	453.5	34.1	65.9		328.5	39.4	60.6	351.6
21.0	79.0	364.7	51.2	43.5	5.3	389.2			

* Deduced from observations at various temperatures; *cf.* Table 3. Heuse (48) gives $V_0 = 378$. † Low (58) finds 490 to 515; Zoch (113) gives 490.4.

TABLE 3.—VELOCITY OF SOUND IN GASES AND VAPORS: VARIATION WITH TEMPERATURE

The empirical equation $V = V'\sqrt{1 + \alpha t 10^{-3} + \beta t^2 10^{-6}}$ should not be used beyond the "range" indicated; when β is not zero, its value is given in a foot-note. Δ_a = average departure of the submitted data from the value given by the empirical formula. The pressure is not always explicitly stated by the observer; it is assumed to be 1 atm. unless another value is indicated. Unit of V' = 1 m/sec; of Δ_a = 1 % V'. Temperature = t, °C.

Symbol	Substance	V'	α	Range	Δ_a	Lit.
	Air, *v.* Table 1					
A	Argon	307.8	3.677	0° to 1000°	0.1	(23, 45)
Hg	Mercury*	$V_{330} = 187.0$; $V_{360} = 208.1$				(54, 56)
I	Iodine*	107.7	3.937	0° to 290°	0.9	(56, 88, 91)
N	Nitrogen	337.7	3.586	0° to 1000°	0.1	(11, 23, 75, 79, 80)
O	Oxygen	316.2	3.781	−184.7° to 21°	†	(19, 26, 75)
	Oxygen	300.8	3.652	−184.7° to −28.4°	1.0	(19)
H_2O	Water	$V_0 = 401$; $V_{93} = 402$; $V_{96} = 410$				(49, 65)
	Water	$V_{110} = 413$;* $V_{120} = 417.5$;* $V_{130} = 424.4$*				(98)
	Water	$V_{100} = 471.5$; $V_{1000} = 853.9$				(82)
NH_3	Ammonia	414.8	3.716	0° to 86°	0.1‡	(24, 65, 80, 112)
N_2O	Nitrous oxide	$V_{14.5} = 264.6$; $V_{600} = 446.9$				(82)
CO_2	Carbon dioxide	258.0	3.630	0° to 1080°	0.0‡	(11)
	Carbon dioxide	258.4	3.534§	0° to 600°	0.0	(23)
	Carbon dioxide	$V_{15} = 264.7$; $V_{1000} = 523.4$				(82)
CS_2	Carbon disulfide	195.0‖	2.126	0° to 70°	0‡	(5, 56)
$CHCl_3$	Chloroform	$V_{20} = 155$; $V_{63} = 144.5$; $V_{80} = 163$; $V_{99.8} = 171.4$				(5, 36, 88)
CH_4	Methane	430.5	2.857	0° to 600°	0.2	(23, 65)
CH_4O	Methyl alcohol	$V_{67} = 341.2$; $V_{77} = 325.7$; $V_{99.7} = 350.3$*				(24, 56, 88)
C_2H_4	Ethylene	317.0	3.142§	0° to 89°	0.1	(24, 26, 45, 65, 80, 112)
C_2H_6	Ethane	303.0	3.304	10° to 100°	0.1‡	(23)
C_2H_6O	Ethyl alcohol	230.6	4.10	0° to 99.8	1.1‡	(24, 56, 65, 70, 88)
$C_4H_{10}O$	Ethyl ether	180.6	1.250§	0° to 100	0.4‡	(5, 24, 49, 65, 93)
$C_4H_{10}O$	Butyl alcohol	$V_{82} = 225.6$; $V_{116} = 235.4$				(56)
C_5H_{12}	Pentane	163.9	10.16§	43° to 86°	0.1	(24)
C_6H_6	Benzene	$V_{15} = 193$; $V_{90} = 200$; $V_{100} = 205$				(5, 24, 88)

* At pressure of saturated vapor.

† For 0°, 21°, and −184.7°, Δ_a = 0.2; at −28.4°, −66.5°, and −137.3° computed V too great by 5.5 %, 3.4 %, and 4.1 %, respectively.

‡ The following values have been omitted: NH_3, $V_0 = 407.4$ (72), low 1.8 %. CO_2, $V_{20} = 257.3$ (58), = 259.8 (93), low 3.7 % and 2.7 %. CS_2, $V_0 = 189$ (65), $V_{48} = 187.7$ (36), low 3.1 % and 8.3 %. C_2H_6, $V_0 = 378$ (45), high 25 %. C_2H_6O, $V_{48} = 235.7$ (49), low 6.6 %. $C_4H_{10}O$ (ether), $V_{17} = 175.9$ (58) and $V_{35} = 180.0$ (36), low 4.0 % and 3.8 %; $V_{36} = 192.8$ (58) and $V_{37} = 194.4$ (70), high 2.8 % and 3.5 %.

§ Values of β: CO_2, −0.210; C_2H_4, 24.6; $C_4H_{10}O$ (ether), 25.0; C_5H_{12}, −37.6.

‖ $V_{99.7} = 223.2$ (88), high 4.4 %; at pressure of saturated vapor.

Table 4.—Velocity (V) of Sound in Liquids

Pure liquids; aqueous solutions; ill-defined liquids. In column C is given either the density (g/cm³) or the wt. % of the solute; temperature = t, °C. Unit of V = 1 m/sec.

Pure Liquids

Symbol	Substance	t	V_t	Lit.
Hg	Mercury	20	1407	(13)
H_2O	Water, distilled, air-free	15	1447*	(25)
		4	1419.2	(13)
		21.5	1483.6	(13)
	Water, pure	15	1433†	(64)
	Natural waters, *v.* Table 5.			
HNO_3	Nitric acid	15.5	1518	(25)
		16	1425	(76)
CS_2	Carbon disulfide	15	1161	(25)
		20	1160	(76)
$CHCl_3$	Chloroform	15	983	(25)
CH_3NO_2	Nitromethane	21.0	1360.5	(14)
CH_4O	Methyl alcohol	19.0	1143.2	(14)
C_2H_6O	Ethyl alcohol	8.4	1264	(64)
		15	1275	(76)
		23	1160	(105)
C_3H_6O	Acetone	20.5	1189.4	(14)
$C_4H_{10}O$	Ethyl ether	0	1152	(64, 105)
		15	1024	(25, 76)
$C_5H_{12}O$	Amyl alcohol	20.0	1269.8	(14)
C_6H_5Cl	Chlorobenzene	17.0	1315.4	(14)
$C_6H_5NO_2$	Nitrobenzene	17.5	1506.1	(14)
C_6H_6	Benzene	16.3	1170	(76)
		17	1166‡	(25)
C_6H_7N	Aniline	20.8	1675.7	(14)
$C_6H_{12}O_3$	Paraldehyde	21.5	1202.4	(14)
C_6H_{14}	*n*-Hexane	21.0	1111.7	(14)
$C_7H_7NO_2$	*o*-Nitrotoluene	20.5	1482.0	(14)
C_7H_8	Toluene	20.5	1327.2	(14)
C_7H_8O	*m*-Cresol	21.5	1492.5	(14)
C_7H_9N	*o*-Toluidine	21.0	1644.8	(14)
	m-Toluidine	21.6	1602.4	(14)
C_8H_{10}	Ethylbenzene	20.0	1351.0	(14)

Aqueous Solutions

Solute	C	t	V_t	Lit.
HCl	1.207	15.5	1518	(25)
		16	1455	(76)
H_2SO_4	7%	18.5	1455	(76)
	31%	19.7	1475	(76)
	63%	19.6	1380	(76)
	92%	20.6	1280	(76)
NH_3	2.8%	15	1440	(76)
	7.3%	15	1470	(76)
	17.5%	15	1540	(76)
	23%	15	1635	(76)
	0.880	16	1663	(25)
C_2H_5OH	11%	4.4	1496	(64)
	95%	12.5	1241	(25)
	95%	20.5	1213	(25)
$ZnSO_4$	8%	16	1445	(76)
	30%	13	1465	(76)
	41%	17.5	1510	(76)
$CuSO_4$	1.0663	21.5	1513.0	(13)
	1.1238	21.5	1538.5	(13)
	1.1615	21.5	1562.3	(13)
$FeSO_4$	1.104	16.5	1485	(76)
$CaCl_2$	1.0661	21.5	1546.9	(13)
	1.1271	21.5	1601.3	(13)

Aqueous Solutions.—(Continued)

Solute	C	t	V_t	Lit.
$CaCl_2$.—(*Continued*)	1.1942	21.5	1672.0	(13)
	43%	22.5	1980	(105)
$BaCl_2$	1.0662	21.5	1503.6	(13)
	1.1256	21.5	1524.4	(13)
	1.1970	21.5	1547.6	(13)
NaCl	10%	15	1470	(25)
	15%	15	1530	(25)
	20%	15	1650	(25)
	Conc.‖	14.7	1661	(64)
	Conc.‖	18.1	1561	(105)
	1.0662	21.5	1586.1	(13)
	1.1259	21.5	1676.1	(13)
	1.1971	21.5	1784.6	(13)
Na_2SO_4	5.3%	18.6	1491	(76)
	6%	19.4	1474	(76)
	11.7%	17.3	1508	(76)
	11.8%	20	1525	(105)
	Conc.‖	19	1584	(105)
	Conc.‖	14.7	1528	(64)
$NaNO_3$	Conc.‖	15.3	1650	(64)
	Conc.‖	20.9	1670	(105)
Na_2CO_3	Conc.‖	22.2	1594.4	(105)
KOH	12%	15.7	1430	(76)
	19%	19.1	1580	(76)
	29%	19.7	1620	(76)
KNO_3	Sat.¶	14.4	1515	(64)

Ill-defined Liquids

Liquid	t	V_t	Lit.
Gasoline	7.4	1395	(64)
Petroleum	7.4	1395	(64)
	15	1326	(64)
Turpentine	3.5	1371	(64)
	15	1326	(25)
	24	1212	(105)

* V_t = 1398 + 3.28t from 13° to 31° (25).
† V_t = 1383 + 3.33t from 3.9° to 25.2° (64).
‡ Author calls it "Benzin," does not give formula.
‖ Described as "concentrated;" perhaps saturated was meant.
¶ Saturated solution.

Table 5.—Velocity (V) of Sound in Natural Waters

In all oceans, the average vertical velocity for depths of 3.5 to 8.0 km is 1528 to 1529 m/sec; for lesser depths, it is less; values computed from density and adiabatic compressibility by method of Heck and Service (41) may differ by 20 m/sec from the actual value (41). Unit of V = 1 m/sec; of depth = 1 m; temperature = t, °C.

Water	Depth	Salt	t	V	Lit.
Lake Geneva			8.1	1435	(18)
Seine River			15	1437	(105)
			30	1528	(105)
			50	1652.2	(105)
			60	1724.7	(105)
Ocean: Horizontal Velocity					
Open ocean	13	3%*	14.5	1503.5	(63)
Block Island Sound, N. Y.	30	3.35%	3.0	1453.3	(87)
Long Island Sound, N. Y.	30		13	1492.3	(29)
Isle of Wight		3.51%	6	1474	(110)
		3.52%	7	1478	(110)
		3.5%	16.95	1511	(110)

TABLE 5.—(*Continued*)

Water	Depth	Salt	t	V	Lit.
Ocean: Vertical Velocity					
North Atlantic	1288			1520	(41)
Caribbean Sea	338			1478	(41)
	1771			1486	(41)
Pacific	1185			1505	(41)
	2962			1493	(41)
All oceans	3500 to 8000			1528	(41)

* Density at 14.9° = 1.0245 g/cm³.

TABLE 6.—VELOCITY (V) OF SOUND IN SOLIDS

Pure metals; alloys; papers, fabrics, and skins; woods; miscellaneous. Either room temperature or t, °C. Unit of V = 1 m/sec.

Metals	t	V	Lit.
Pure Metals			
Ag		2645	(65)
	18	2608*	(105)
	10	2678†	(105)
	20	2678†	(105)
	100	2640†	(105)
	200	2480†	(105)
Al		5105	(65)
Au	(?)	2082	(65)
	10	2112†	(105)
	20	1743*	(105)
	100	1720*	(105)
	200	1735*	(105)
Cd		2307	(65)
Co		4724	(65)
Cu	20	3560	(105)
	100	3290	(105)
	200	2950	(105)
	(?)	3825	(65)
		3984	(16)
Fe	20	5130	(105)
	100	5300	(105)
	200	4720	(105)
	(?)	5016	(65)
	15	4913	(105)
Steel	18	4982‡	(105)
	10	4940§	(65)
		5093§	(54)
	20	4990‖	(105)
	100	4920‖	(105)
	200	4790‖	(105)
Mg		4602	(66)
Ni		4973	(65)
Pb		1322	(65)
	18	1229*	(105)

Metals	t	V	Lit.
Pure Metals.—(Continued)			
Pd	10	3074	(105)
		3257	(65)
Pt	(?)	2792	(65)
	20	2690	(105)
	100	2570	(105)
	200	2460	(105)
	18	2688*	(105)
	10	2736†	(105)
Sn	13	2490	(35)
		2490	(16)
		2640	(65)
Zn	13	3681	(35)
		3699	(65)
Alloys			
Brass		3479	(65)
		3617	(54)
		3235¶	(105)
Steel	*See above*, Fe		

	x	V	Lit.
Zn-Sn	0	3681	(35)
(13°C, x atoms	1	3338	
Sn to 5	2	3195	
atoms Zn)	3	3100	
	4	3032	
	5	2980	
	6	2940	
	7	2898	
	8	2850	
	9	2785	
	10	2710	
	∞	2490	

Papers, Fabrics, Skins (66)

The velocity in a given specimen depends upon the tension. All the membranous materials were cut in strips 15 mm wide ((66), p. 575), but neither their thicknesses nor the diameters of the cords are stated. The velocity was observed while the strip, or cord, carried a longitudinal load of w kg.

Material	w	V
Cord: Cotton	1	1425
Linen	1	1815
	2	1942
Oilcloth	1	559

Papers, Fabrics, Skins.—(Continued)

Material	w	V
Paper: Blotting	0.5	1627
Parchment	0.7	2198
Silvered	0.6	2575
Straw	0.5	1617
Tissue	0.1	1989
Tracing	0.7	2278
Writing	0.9	2107
Parchment: French	2	1860
German	1.5	1636
Satin ribbon	1	2015
Sheepskin	0.1	471

Woods

$V_\parallel$, V_r, V_c = velocity parallel to grain, radial velocity, circumferential velocity; unit = 1 m/sec. d = density; unit = 1 g/cm³.

Wood	d	V_c	V_r	$V_\parallel$	Lit.
Ash		1260	1390	4670	(105)
	0.542			4272	(46)
	0.562			3657	(46)
Beech		1415	1840	3340	(105)
				3412	(66)
Cedar	0.455			3975	(46)
	0.465			4926	(46)
Cherry				4410	(46)
Elm		1013	1420	4120	(105)
Fir				5256	(86)
				4179	(66)
Fir: Red				4274	(46)
White				4640	(46)
Mahogany				4135	(46)
Maple				4110	(105)
Oak				3381	(66)
Oak: Red				4180	(46)
White				4316	(46)
Pine				3320	(105)
Poplar				4280	(105)
Sycamore				4460	(105)
Walnut				4781	(46)

Miscellaneous Materials

$\left\{\begin{matrix}430\\530\end{matrix}\right.$ indicates that V ranges from 430 to 530 m/sec

Material	t	V	Lit.
Beeswax	15	880	(86)
	16	863	(103)
	28	450	(86)
Brick		3652	(16)
Caoutchouc, vulcanized: Black	0	54	(31)
	50	30.7	(31)
Red	0	69.3	(31)
	57	36.6	(31)
	70	33.9	(31)
Gray	0	43.2	(31)
	45	32.3	(31)
Tubing		27	(86)
Very hard		150	(86)
Cork		430	(86)
		530	
Ebonite	15	1573	(15)
Gelatin		1364	(44)
		1626	
Glass		5991	(86)
		5060	(54)
	16	5202	(103)

Miscellaneous Materials.—(Continued)

Material	t	V	Lit.
Glass: Soda		5000	**
		5300	
Flint		4000	**
Granite		3950	(37)
Ivory		3013	(17)
Marble		3810	(37)
Paraffin	6.1	1522	(84)
	16	1304	(103)
	17.3	1419	(84)
	21.6	1325	(84)
	25.2	1192	(84)
	27.8	1035	(84)
	29.3	851	(84)
	30.5	748	(84)
	32.9	470	(84)
	35.3	250	(84)
Rock (±700 m/sec)		2500	(4)
Sand (±600 m/sec)		2000	(4)
Sealing wax		1320	(86)
Shellac, white		1320	(86)
	8.7	1009	(84)
	26.3	869	(84)
	40	762	(84)
Slate		4510	(37)
	4.9	1517	(84)
Spermaceti	33.1	1091	(84)
Stearin	16	1378	(103)
	16.1	1354	(84)
	33.6	1181	(84)
	48.2	911	(84)
Suet	18	460	(86)
Tallow	16	390	(103)
Tuff		2850	(37)
Wax (*v.* Beeswax)			

* Soft.
† Hard.
‡ Mild steel.
§ Blue tempered steel.
‖ Cast steel.
¶ Unannealed.
** Various observers.

Table 7.—Velocity of Sounds in Gases Confined in Tubes

The velocity of sound in a gas contained in a tube depends upon the heat conductivity of, and the velocity of sound in, the material of the tube, upon the viscosity and the heat conductivity of the gas, upon the character of the inner surface of the tube, upon the rate and the direction at which heat and vibrations are transferred between the tube and external objects, upon the pitch and intensity of the sound, and upon the thickness and diameter of the tube (27, 32, 42, 51, 69, 72, 77, 78, 81, 93). If the inner surface of the tube is smooth, and if the transfer of energy to external objects is negligible, the velocity is given by the expression $V = V_\infty(1 - K/D\sqrt{n})$, where D = diameter, n = pitch, K depends upon the properties of the tube and gas, and V_∞ = velocity in an unlimited volume of the gas. Under other conditions, this expression may be multiplied by a quantity depending upon the material and dimensions of the tube, and K may involve D and n. Some observers (77, 81) claim $V = V_\infty(1 - K/Dn^{2/3})$, another (108) concludes that the exponent of n is 0.53.

For air in iron and in porcelain (72, 93), $D \geq 4$ cm, n = 500, 600, and "explosion," V differs but little from its value in free air; *see also* (99). When other observations are represented by the following equations, δ has the values tabulated:

Air in glass, $D > 0.6$ cm (54, 58, 69, 81), $V = 331.0(1 - 0.501/D\sqrt{n})(1 + \delta)$.

Air in glass, $D < 0.4$ cm (78), $V = 331.0(1 - 0.441/D\sqrt{n}) \times (1 + \delta)$.

Air in brass, $D > 1$ cm (6), $V = 331.0(1 - 0.362/D\sqrt{n}) \times (1 + \delta)$.

Air in brass, $D < 0.2$ cm (78), $V = 331.0(1 - 0.834/D\sqrt{n}) \times (1 + \delta)$.

CO_2 in glass (93), $V = 260.0(1 - 0.452/D\sqrt{n})(1 + \delta)$.

H_2 in glass (93), $V = 1249.5(1 - 0.262/D\sqrt{n})(1 + \delta)$.

Unit of δ = 0.001; of D = 1 cm; of n = 1 double vibration per sec.

Air in glass									Air in brass			
n	256	320	384	512	1023	1850	2482	5550	n	256	384	512
D	δ								D	δ		
0.101			+3	− 8					0.099		0	0
0.151			+2	+ 6					0.148		−25	+16
0.34		+32		+35					1.17	0		
0.68							−2		1.95	−1		
0.93	+2			+ 2	−0				3.25	+0		
1.3						+5		+5	5.41	+0		
1.71	+1			0	−1				8.82	0		
2.80	0			− 0	−2							
5.5								+7				

CO_2 in glass						H_2 in glass			
D	0.21	0.35	0.53	1.02	2.11	0.35	0.53	1.02	2.11
n	δ					δ			
705		−0	−1	−3	−1				
1943	+4	0	−2	−3	+4				
3755	+6	+4	−1	−3	+5	−0	+1	−0	+9

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abbott and Cook, *2*, **16**: 486; 20. (2) Cassini de Thury, *151*, **1738**: 128. (3) Angerer and Ladenburg, *8*, **66**: 293; 22. (4) Barre and Schnell, *34*, **180**: 1415; 25. (5) Beyme, *Diss.*, Zürich, 1884. (6) Blaikley, *3*, **16**: 447; 83. **18**: 328; 84. (7) Bosscha, *8*, **92**: 485; 54. *553*, **21**: 533; 62. (8) Boyle and Taylor, *69*, **19 III**: 197; 25. (9) Boys, *204*, **16**: 199; 92.
(10) Bravais and Martins, *6*, **13**: 5; 45. *8*, **66**: 351; 45. (11) Buckendahl, *Diss.*, Heidelberg, 1906. (12) Bureau des Longitudes, *6*, **20**: 210; 1822. *Euvres de Arago, Mem. Sci.* ii: 1. (13) Bungetziano, *Bull. soc. Romaine sci.*, **22**: 182; 13. (14) Busse, *8*, **75**: 657; 24. (15) Campanile, *59*, **1**: 259; 95. *71*, **33**: 63; 94. (16) Chladni, *Die Akustik*. Breitkopf und Härtel, Leipzig, 1802. (17) Ciccone and Campanile, *71*, **30**: 187; 91. (18) Colladon and Sturm, *6*, **36**: 113, 225; 1827. *8*, **12**: 39, 161; 1828. (19) Cook, *2*, **23**: 212; 06.
(20) Czuker, *88*, **17**: 261; 15. (21) Darrow, *2*, **7**: 413; 16. (22) Dieckmann, *Diss.*, Berlin, 1908. *8*, **27**: 1066; 08. (23) Dixon, Campbell and Parker, *5*, **100**: 1; 21. (24) Dixon and Greenwood, *5*, **105**: 199; 24. **109**: 561; 25. (25) Dorsing, *Diss.*, Bonn. *8*, **25**: 227; 08. (26) Dulong, *6*, **41**: 113; 1829. *8*, **16**: 438; 1829. (27) Dvorak, *8*, **154**: 156; 75. (28) Earnshaw, *8*, **19**: 449; 60. **20**: 37, 186; 60. (29) Eckhardt, *2*, **24**: 452; 24.
(30) Esclangon, *34*, **168**: 165; 19. (31) Exner, *75*, **69 II**: 102; 74. (32) Foley, *2*, **14**: 143; 19. **16**: 449; 20. *Proc. Indiana Acad. Sci.*, **1918**: 205. (33) Foley, *Proc. Indiana Acad. Sci.*, **37**: 205; 27. (34) Frot, *34*, **127**: 609; 98. (35) Gerosa, *22*, **4 I**: 127; 88. (36) Gerosa and Maï, *22*, **4 I**: 728; 88. (37) Gray and Milne, *Smithsonian Physical Tables*. (38) Greely, *Proc. U. S. Expedition to Grinnel Land*. Washington, 1888. *507*, **7**: 6; 90. *8*, **30**: 507; 90. (39) Grüneisen and Merkel, *8*, **66**: 344; 21.
(40) Hebb, *2*, **20**: 89; 05. **14**: 74; 19. (41) Heck and Service, *217*, **Pub. No. 108**; 24. (42) Helmholtz, *549*, **3**: 16; 65. (43) Helmholtz, *Wiss. Abhandlungen*, **I**. Leipzig, Barth, 1882. (44) Herbolsheimer, *96*, **3**: 182; 20. (45) Heuse, *8*, **59**: 86; 19. (46) Ihlseng, *12*, **17**: 125; 79. (47) Irons, *3*, **3**: 1274; 27. (48) Jacques, *12*, **17**: 116; 79. (49) Jäeger, *8*, **36**: 165; 89.
(50) Kayser, *8*, **2**: 218; 77. **6**: 465; 79. (51) Kirchhoff, *8*, **134**: 77; 68. (52) Koch, *8*, **26**: 551; 08. (53) Krajevitsch, *53* (*Phys. Sect.*), **17**: 335; 85. (54) Kundt, *551*, **1865**: 234. **1867**: 858. *8*, **127**: 497; 66. **135**: 337, 527; 68. (55) Küpper, *8*, **43**: 905; 14. (56) Lechner, *75*, **118 IIA**: 1035; 09. (57) Leroux, *34*, **64**: 392; 67. *6*, **12**: 345; 67. *3*, **33**: 398; 67. (58) Low, *8*, **52**: 641; 94. (59) McAdie, *Annals, Astron. Obs. Harvard*, **86, pt. 2**: 107; 23.
(60) Mach and Mach, *8*, **41**: 140; 90. (61) Mach and Sommer, *75*, **75 II**: 101; 77. (62) Mach, Tumlirz and Kögler, *75*, **77 II**: 7; 78. (63) Marti, *34*, **169**:

ERRATA

VOLUME I

PAGE

103 **THE CRYSTALLINE STATE.** Specific heat. *For* 1 joule = 4.185 cal *read* 1 cal = 4.185 joule.
104 Column headed *A*, line Se. *For* 1.2 *read* 12.
110 Index No. 246. *For* Mol. wt. 118.091 *read* 132.109.
194 Index No. 1101. *For* $CH_3(C_3H_7)CH_2NH_2$ *read* $CH_3(C_3H_7)$-$CHNH_2$.

PAGE

215 Index Nos. 2387 to 2394. *Add note:* For more accurate data, *see 1*, **51**: 1544; 29.
240 Index No. 3993. Column headed *d*. *Add:* At 0°C.
295 *For* Isohydroxydimethylurea *read* Isohydroxydimethyluric acid.
306 *After* **−5**: *delete* 46. *After* **2**: *insert* 46.

ERRATA

VOLUME II

PAGE

167 Last line. *Transpose* 27.2 *from fourth to third column under* CO.
340 Line at head of table. *Add:* For temperature = 17.5°C.
415 Diagram for Na-Pb. *Add literature reference:* Calingaert and Boesch, *1*, **45**: 1901; 23.

PAGE

418 Zn-Sn-Bi and Pb-Sn-Bi diagrams. *Add note:* For best values of the binary eutectics, *see* the binary diagrams, p. 414 and p. 416.

ERRATUM

VOLUME III

PAGE

20 **O.**—*For* 1.447 at the B. P. *read* 1.1447.

ERRATA

VOLUME IV

PAGE

166 Index No. 1826. *At* 54.0°C *for* 51.8 *read* 58.1 Wt. % A.
242 *For* $K_2SO_4.Cr_2(SO_4)_3$ *read* $KCr(SO_4)_2$.
248 Literature citation (175). *For* 01 *read* 00.

PAGE

470 $C_8H_{18}O$, Octyl alcohol. *For* column head M/g H_2O *read* M/kg H_2O.

ERRATA

VOLUME V

PAGE

54 Second column. CHANGE IN RADIUS WITH TIME. Column 2. For Air *read* CO_2.
80 Å-TABLE. Air. γ at −79°C. *For* 3.33 *read* 2.33.
93 Literature citations for Ir. *For* (3) *read* Behn, *8*, **66**: 237; 98 *and for* (85) *read* Violle, *34*, **89**: 702; 79.
113 H_2O, Water. In Note: *for* increased *read* decreased *and for* 4.185 cal_{15} *read* 1 cal_{15} = 4.185 joule.
147 **HEAT OF ISOTHERMAL COMPRESSION.** *For* 10^5Q *read* 10^4Q.

PAGE

248 **SYMBOLS AND NUMERICAL RELATIONS.** Definitions for k and k_θ. *For* λ_0 *read* λ. Definition for n. *For* λ_0/λ *read* λ/λ_m. Column 2, line 15. *For* λ *read* λ_m. Line 16. *For* λ_0 *read* λ.

249–252 inclusive. Introductions to Tables 1 to 4 inclusive. *For* λ_0 *read* λ.

358 Literature citation (458). *For* 237 *read* 637.
388 Figure 1. *For* $\frac{1}{3}Ca_2(PO_4)_3$ *read* $\frac{1}{3}Ca_3(PO_4)_2$.

PASTE ON INSIDE COVER

Key Numbers of Elements

| | | |

281; 19. (64) Martini, *24*, **12**: 566; 88. **7**: 491, 639; 81. **4**: 1113; 92. *59*, **18**: 439; 09. *51*, **8**: 915; 09. (65) Masson, *34*, **44**: 464; 57. *8*, **103**: 272; 58. (66) Melde, *8*, **45**: 568, 729; 92. (67) Miller, *2*, **17**: 255; 21. (68) Moll and van Beek, *62*, **114**: 424; 1824. *8*, **5**: 351, 469; 1825. (69) Müller, *Diss.*, Bonn, 1902. *8*, **11**: 331; 03.

(70) Neyreneuf, *51*, **3**: 209; 84. **4**: 550; 85. *34*, **98**: 980, 1264; 84. *6*, **9**: 535; 86. **2**: 251; 94. (71) Pierce, *65*, **60**: 271; 25. (72) Regnault, *34*, **66**: 209; 68. *3*, **35**: 161; 68. (73) Riemann, *188*, **1859**: 192. *Gesammelte mathematische Werke*. Leipzig, Teubner, 1876. (74) Rowland, *Physical Papers*, **1902**: 411. Baltimore, Johns Hopkins Press. (75) Scheel and Heuse, *8*, **37**: 79; 12. **40**: 473; 13. (76) Schmidt, *75*, **114** IIa: 945; 05. (77) Schneebeli, *8*, **136**: 296; 69. (78) Schulze, *548*, **1903**: 59. *8*, **13**: 1060; 04. (79) Schulze and Rathjen, *8*, **49**: 457; 16.

(80) Schwiekert, *8*, **48**: 593; 15. (81) Seebeck, *8*, **139**: 104; 70. **149**: 129; 73. *6*, **4**: 19, 510; 70. (82) Shilling, *3*, **3**: 273; 27. (83) Smith, *5*, **45**: 451; 89. (84) Smoluchowski, *75*, **103** IIa: 739; 94. (85) Stampfer and von Myrbach, *8*, **5**: 496; 1823. (86) Stefan, *75*, **57** II: 697; 68. **65** II: 419; 72. (87) Stephenson, *2*, **21**: 181; 23. (88) Stevens, *Diss.*, Heidelberg, 1900. *8*, **7**: 285; 02. (89) Stoletov, *53* (*Phys. Sect.*), **18**: 65; 86.

(90) Stone, *3*, **43**: 153; 72. *62*, **162**: 1; 72. (91) Strecker, *8*, **13**: 20; 81. **17**: 85; 82. (92) Strieder, *88*, **16**: 615; 14. (93) Sturm, *Diss.*, Bonn, 1904. *8*, **14**: 822; 04. (94) Szathmàri, *8*, **2**: 418; 77. (95) Thiesen, *8*, **25**: 506; 08. *243*, **27**: 112; 07. **23**: 114; 03. **24**: 133; 04. **25**: 102; 05. **26**: 111; 06. (96) Threlfall and Adair, *5*, **45**: 450; 89. **46**: 496; 90. (97) Toepler, *8*, **14**: 838; 04. (98) Treitz, *Diss.*, Bonn, 1903. (99) Vautier, *16*, **6**: 311; 26.

(100) Vieille, *34*, **127**: 41; 98. (101) Violle, *34*, **127**: 904; 98. *Rapports pres. au Congr. Intern. physique*, **1**: 228; 00. (102) Violle and Vautier, *34*, **102**: 103; 86. **106**: 1003; 88. **110**: 230; 90. **120**: 1402; 95. **121**: 51; 95. **140**: 1292; 05. *6*, **5**: 208; 05. (103) Warburg, *8*, **136**: 285; 69. (104) Wenz, *8*, **33**: 951; 10. (105) Wertheim, *6*, **12**: 385; 44. *8*, **77**: 427; 49. (106) Westphal, *88*, **16**: 13, 613; 14. (107) Witkowski, *165*, **1899**: 138. (108) Wold and Stibitz, *166*, **66**: 381; 27. (109) Wolff, *8*, **69**: 329; 99.

(110) Wood and Browne, *67*, **35**: 183; 23. (111) Wood and Loomis, *3*, **4**: 417; 27. (112) Wüllner, *8*, **4**: 321; 78. (113) Zoch, *8*, **128**: 497; 66.

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United States and Canada: "Periodicals Abstracted by Chemical Abstracts, 1926" (Chemical Abstracts, Ohio State Univ., Columbus, Ohio); "Union List of Serials in the Libraries of the United States and Canada, 1927" (H. W. Wilson & Co., New York City); "A Catalogue of Scientific Periodicals in Canadian Libraries, 1924" (McGill Univ., Montreal, Canada).

Great Britain: "A World List of Scientific Periodicals Published in the Years 1900–1921" (Oxford Univ. Press, London, 1925–).

Holland: "Chemisch Jaarboekje tevens Jaarboekje der Nederlandsche Chemische Vereeniging, Vol. 3." (Amsterdam, D. B. Centen, 1920).

1. Journal of the American Chemical Society.
2. Physical Review.
3. London, Edinburgh and Dublin Philosophical Magazine and Journal of Science.
4. Journal of the Chemical Society, London. (Memoirs of the Chemical Society; *continued as* Quarterly Journal; *later* Journal.)
5. Proceedings of the Royal Society (London). A. Mathematical and Physical Sciences.

5B. Proceedings of the Royal Society (London). B. Biological Sciences.

6. Annales de chimie et de physique. (*Divided into* Nos. 14 and 16 *in 1914*).
7. Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre.
8. Annalen der Physik. [Journal der Physik, 1790–1794. Neues Journal der Physik, 1795–1796. Annalen der Physik, 1799–1819; Annalen der Physik und der physikalischen Chemie, 1819–1824 (Gilbert). Annalen der Physik und Chemie, 1824–1899 (Poggendorff, Wiedemann). Annalen der Physik, 1900– (Drude, Wien and Planck).]
9. Zeitschrift für Elektrochemie und angewandte physikalische Chemie.
10. Tables annuelles internationales de constantes et données numériques.
11. American Chemical Journal. (*Combined with* No. 1 *in 1914*.)
12. American Journal of Science. (American Journal of Science and Arts, 1820–79; *known also as* Silliman's Journal of Science.)
13. Annalen der Chemie, Justus Liebig's.
14. Annales de chimie.
16. Annales de physique.
17. Anzeiger der Akademie der Wissenschaften in Wien. Mathematisch-naturwissenschaftliche Klasse.
18. Archives néerlandaises des sciences exactes et naturelles. Séries IIIA (Sciences exactes).
19. Arkiv för Kemi, Mineralogi och Geologi.
20. Arkiv för Matematik, Astronomi och Fysik.

21. Astrophysical Journal.
22. Atti della reale accademia nazionale dei Lincei. (Rendiconti classe di scienze fisiche, matematiche e naturali.)
23. Atti della reale accademia delle scienze di Torino.
24. Atti del reale istituto Veneto di scienze, lettere ed arti.
25. Berichte der deutschen chemischen Gesellschaft.
26. Berichte der deutschen physikalischen Gesellschaft. *See also* No. 96.
27. Bulletin de la société chimique de France. (*Before 1908 was* Bulletin de la société chimique de Paris.)
28. Bulletin de la société chimique de Belgique. (*Before 1904 was* Bulletin de l'association belge des chimistes.)
30. Bureau of Mines, Technical Papers.
31. Bureau of Standards, Scientific Papers. (*Continued as* No. 546.)
31A. Bureau of Standards, Bulletin. (*Continued as* No. 546.)
32. Bureau of Standards, Technologic Papers. (*Continued as* No. 546.)
33. Chemical and Metallurgical Engineering. (*Name changed July, 1918 from* Metallurgical and Chemical Engineering.)
34. Comptes rendus hebdomadaires des séances de l'académie des sciences, de l'institut de France.
36. Gazzetta chimica italiana.
37. Helvetica Chimica Acta.
38. Journal of the American Ceramic Society.
38B. Bulletin of the American Ceramic Society.
39. Journal of the American Institute of Electrical Engineers.
40. Journal of the American Institute of Metals. *See* No. 329.
41. Journal of the Chemical Society of Japan (Nippon Kwagaku Kwai Shi). (*Name changed in Jan., 1921 from* Journal of the Tokyo Chemical Society.)
41B. Bulletin of the Chemical Society of Japan.
42. Journal de chimie physique.
44. Journal of the Faculty of Science, Tokyo Imperial University.
45. Industrial and Engineering Chemistry. (*Name changed Jan., 1923 from* Journal of Industrial and Engineering Chemistry.)
46. Journal of the Institution of Electrical Engineers (London).
47. Journal of the Institute of Metals (London).
48. Journal of the Optical Society of America and Review of Scientific Instruments.
50. Journal of Physical Chemistry.
51. Journal de physique et le radium. (*Formed from* Le radium *and* Journal de physique, théorique et appliquée.)
52. Journal für praktische Chemie.
53. Journal of the Russian Physico-Chemical Society. (Chemical part.)
54. Journal of the Society of Chemical Industry.
55. Kolloid-Zeitschrift. (*Formerly* Zeitschrift für Chemie und Industrie der Kolloide.)
57. Monatshefte für Chemie und verwandte Teile anderer Wissenschaften.
58. Nature (London).
59. Nuovo Cimento.
60. Översikt av Finska Vetenskaps-Societetens Förhandlingar. (*Discontinued with* Vol. 64, 1921–22.)
61. Oversigt over det Kongelige Danske Videnskabernes Selskabs Forhandlinger.
62. Philosophical Transactions of the Royal Society of London, Series A, Physical and Mathematical.
62B. Philosophical Transactions of the Royal Society of London, Series B, Biological.
63. Physikalische Zeitschrift, vereinigt mit dem Jahrbuch der Radioaktivität und Elektronik.
64P. Proceedings of the Royal Academy of Sciences of Amsterdam.
64V. Verslag koninklijke Akademie van Wetenschappen te Amsterdam.
65. Proceedings of the American Academy of Arts and Sciences.
66. Proceedings of the American Society for Testing Materials.
67. Proceedings of the Physical Society of London.
68. Proceedings of the Royal Society of Edinburgh.
69. Proceedings and Transactions of the Royal Society of Canada.
70. Recueil des travaux chimiques des Pays-Bas.
71. Rendiconti dell'accademia delle scienze fisiche e matematiche. (Classe della società reale di Napoli.)
72. Rendiconti reale istituto Lombardo di scienze e lettere.
74. Revue de métallurgie.
74E. Revue de métallurgie, Extraits.
75. Sitzungsberichte Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse.
76. Sitzungsberichte der preussischen Akademie der Wissenschaften.
77. Stahl und Eisen.
78. Transactions of the American Electrochemical Society.
80. Transactions of the American Institute of Mining and Metallurgical Engineers.
83. Transactions of the Faraday Society.
86. University of Illinois, Engineering Experiment Station, Bulletin.
88. Verhandlungen der physikalischen Gesellschaft zu Berlin. *See also* No. 96.
89. Wissenschaftliche Abhandlungen der physikalisch-technischen Reichsanstalt.
92. Zeitschrift für angewandte Chemie.
93. Zeitschrift für anorganische und allgemeine Chemie. (*Name changed in 1915 from* Zeitschrift für anorganische Chemie.)
94. Zeitschrift für Krystallographie. (*Name changed in 1921 from* Zeitschrift für Krystallographie und Mineralogie.)
95. Zeitschrift für Metallkunde. (*Formerly* Internationale Zeitschrift für Metallographie.)
96. Zeitschrift für Physik. (Verhandlungen der physikalischen Gesellschaft zu Berlin, 1882–1898; Verhandlungen der deutschen physikalischen Gesellschaft, 1899–1902; Berichte der deutschen physikalischen Gesellschaft, 1903–1919; Zeitschrift für Physik, 1920– .)
97. Zeitschrift für technische Physik.
98. Zeitschrift des Vereines deutscher Ingenieure.
99. Zeitschrift für wissenschaftliche Photographie, Photophysik und Photochemie.
101. Elektrotechnische Zeitschrift.
105. Journal of the Society of Glass Technology.
107. Electrical World.
114. Electric Journal.
115. Engineering.
116. Sibley Journal of Engineering.
117. Scientific Proceedings of the Royal Dublin Society.
119. Proceedings of the American Institution of Electrical Engineers. (*Discontinued in 1919.*)
120. General Electric Review.
121. Electrician.
125. Archiv für Elektrotechnik. (*Supplement to* No. 101.)
126. Bulletin de la société française des électriciens.
128. Journal of the Washington Academy of Sciences.
129. Transactions of the American Institute of Electrical Engineers.
132. Anales de la sociedad española de fisica y quimica.
133. British Association for the Advancement of Science, Reports.
134. Bulletin de l'académie des sciences de l'union des républiques soviétiques socialistes. (*Formerly* Bulletin de l'académie impérial des sciences de St. Pétersbourg; *name changed in 1917 to* Bulletin de l'académie des sciences de Russie; *present name dates from 1925.*)

135. Chemical News and Journal of Industrial Science. (*Name changed in 1921 from* Chemical News and Journal of Physical Science.)
137. Kongelige Danske Videnskabernes Selskab, Mathematisk-fysiske Meddelelser.
139. Ferrum.
140. Journal of the Iron and Steel Institute (London).
141. Journal of Biological Chemistry.
143. Journal of the Franklin Institute.
147. Meddelanden från K. Vetenskapakademiens Nobelinstitut.
148. Zeitschrift für die gesamte Kälte-Industrie.
149. Archives des sciences physiques et naturelles. (Bibliothèque britannique, 1796–1815; Bibliothèque universelle des sciences, belles-lettres et arts, 1816–1835; Bibliothèque universelle de Genève, 1836–1845; Supplément à la bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1846–1847; Bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1848–1857; Bibliothèque universelle, revue suisse et étrangère. Archives des sciences physiques et naturelles, 1858–1861; Bibliothèque universelle et revue suisse. Archives des sciences physiques et naturelles, 1862–1877; Bibliothèque universelle. Archives des sciences physiques et naturelles, 1878– .)
151. Mémoires de l'académie royale des sciences de l'institute de France.
152. Carnegie Institution of Washington, Publications.
154. Iowa Geological Survey, Bulletin.
159. Science Reports of the Tôhoku Imperial University. Series I, Mathematics, Physics and Chemistry.
159B. Science Reports of the Tôhoku Imperial University. Series III, Petrology, Mineralogy and Mineral Deposits.
165. Bulletin internationale de l'académie des sciences de Cracovie. (*Name changed to* Bulletin internationale de l'académie Polonaise des sciences et des lettres.)
166. Science.
168. Communications from the Physical Laboratory at the University of Leiden.
169. Annales de l'Institut Polytechnique Pierre-le-Grand, Pétrograd.
170. Memorie della reale accademia nazionale dei Lincei, Roma.
171. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Klasse. Abteilung A.
172. International Congress of Applied Chemistry.
174. Transactions of the Royal Society of Edinburgh.
175. Annales academiae scientiarum fennicae.
176. Chemisch Weekblad (Amsterdam).
177. Annales scientifiques de l'université de Jassy.
178. Archivio di fisiologia (Florence).
182. Proceedings of the Chemical Society, London.
186. Bulletin de la classe des sciences, académie royale de Belgique.
187. Metall und Erz, Zeitschrift für Metalhüttenwesen und Erzbergbau, einschl. Aufbereitung.
188. Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen. Geschäftliche Mitteilungen; mathematisch-physikalische Klasse.
189. Centralblätt für Mineralogie, Geologie und Paläontologie.
190. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
190B. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage Band.
191. Bulletin de la société française de minéralogie.
192. Metallurgie. (*Divided into* Nos. 139 and 187.)
197. Proceedings of the National Academy of Sciences.
199. Le Radium. (*Merged into* No. 51 *in 1920.*)
200. Jahrbuch der Radioaktivität und Elektronik. (*Combined with* No. 63 *in 1924.*)
201. Proceedings of the Cambridge Philosophical Society.
202. Zeitschrift für physiologische Chemie.
204. Photographic Journal.
205. Biochemische Zeitschrift.
208. Physica, Nederlandsch Tijdschrift voor Natuurkunde.
211. Abhandlungen der mathematisch-physischen Klasse der sächsischen Akademie der Wissenschaften zu Leipzig.
213. Sitzungsberichte der mathematisch-physikalischen Klasse der bayerischen Akademie der Wissenschaften zu München.
214. Kongelige Danske Videnskabernes Selskab, Skrifter naturvidenskabelig og mathematisk Afdeling.
215. Lunds Universitets Årsskrift.
217. U. S. Coast and Geodetic Survey, Special Publications.
218. Naturwissenschaften.
219. Proceedings of the Physico-Mathematical Society of Japan.
221. Berichte über die Verhandlungen der sächsischen Akademie der Wissenschaften zu Leipzig. Mathematisch-physische Klasse.
231. U. S. Public Health Service, Public Health Reports.
236. Ergebnisse der Physiologie.
237. Fortschritte der Chemie, Physik und physikalischen Chemie.
241. Proceedings of the American Philosophical Society.
242. Vierteljahrsschrift der naturforschenden Gesellschaft, Zürich.
243. Zeitschrift für Instrumentenkunde.
250. Bulletin de séances de la société française de physique (1873–1910). *From 1873–1901 as Its* Séances; *continued as* No. 51.)
268. Terrestrial Magnetism.
269. Mineralogical Magazine and Journal of the Mineralogical Society.
273. Berichte der deutschen pharmazeutischen Gesellschaft. *See also* No. 293.
278. Archiv für die gesamte Physiologie des Menschen und der Tiere. (Pflüger.)
281. Zeitschrift für Psychologie und Physiologie der Sinnesorgane.
284. Journal of the American Pharmaceutical Association.
285. Journal of Mathematics and Physics (Massachusetts Institute of Technology).
286. Chemical Reviews.
289. Journal of Physiology.
290. Journal of the Society of Dyers and Colourists.
291. Arbeiten aus dem Reichsgesundheitsamte.
292. Proceedings and Transactions of the Nova Scotian Institute of Science.
293. Archiv der Pharmazie. (*Combined with* No. 273 *in 1924 to form* Archiv der Pharmazie und Berichte der deutschen pharmazeutischen Gesellschaft.)
294. Mémoires de l'académie de Belgique.
313. United States Bureau of Mines. Reports of Investigations.
325. Proceedings of the Royal Institution of Great Britain.
327. Annales de la société scientifique de Bruxelles.
329. Mining and Metallurgy. (Transactions of the American Brass Founders' Association, 1908–11; Transactions of the American Institute of Metals, 1912–16; Journal of the American Institute of Metals, 1917–18; *discontinued in 1918 and incorporated with* Bulletin of the American Institute of Mining Engineers; *with* No. 148, *1919, this Bulletin became* Bulletin of the American Institute of Mining and Metallurgical Engineers; *with* No. 154, *1919, name changed again to* Mining and Metallurgy.)
337. Bulletin of the National Research Council.
338. Researches of the Electro-Technical Laboratory (Tokyo).
339. American Journal of Mathematics.
362. Chemické Listy pro vedu a prumysl.
365. Bureau of Standards, Circulars.
384. Le génie civil (Paris).
403. Proceedings of the Institution of Mechanical Engineers.

408. Journal de mathématiques pures et appliquées (Paris). (*Continues* Annales de mathématiques pures et appliquées; *present name dates from 1836.*)
417. Iron and Steel Institute, Carnegie Scholarship Memoirs.
420. Bulletin de la société d'encouragement pour l'industrie nationale.
422. American Machinist.
426. Acta societatis fennicae. (*1839–1842*, Commentationes societatis fennicae.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with* Fortschritte der Physik *and* Halbmonatliches Literaturverzeichnis *to form* Physikalische Berichte.)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
434. Scientific Transactions of the Royal Dublin Society.
440. Metal Industry and the Iron Foundry (London).
453. Proceedings of the Iowa Academy of Science.
468. Kongliga Svenska Vetenskaps-Akademien, Handlingar.
481. Tschermak's mineralogische und petrographische Mitteilungen.
502. Archives du Musée Teyler (Haarlem).
506. Monthly Weather Review.
507. Meteorologische Zeitschrift.
512. Proceedings of the Indian Association for the Cultivation of Science.
520. Monthly Notices of the Royal Astronomical Society (London).
523. Gesammelte Abhandlungen zur Kenntnis der Kohle.
524. Abhandlungen der k. Akademie der Wissenschaften, Berlin. (K. preussische Akademie der Wissenschaften.)
529. Proceedings of the Institute of Radio Engineers (New York).
530. American Architect and the Architectural Review.
533. Deutsche Bunsen-Gesellschaft für angewandte physikalische Chemie, Abhandlungen.
534. Proceedings of the National Electric Light Association.
535. Transactions of the International Electrical Congress.
536. Abhandlungen der k. Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse.
537. Gesellschaft zur Beförderung der gesammten Naturwissenschaften (Marburg). Schriften.
539. Proceedings of the Royal Irish Academy. Section A, Mathematical, Astronomical and Physical Science. Section B, Biological, Geological and Chemical Science.
540. Radio Review. (*Now merged into* Wireless World.)
541. Transactions of the Society of Naval Architects and Marine Engineers.
546. Bureau of Standards Journal of Research.
548. Sitzungsberichte der Gesellschaft zur Beförderung der gesammten Naturwissenschaften (Marburg).
549. Naturhistorisch-medizinischer Verein (Heidelberg). Verhandlungen.
551. Monatsberichte der k. preussische Akademie der Wissenschaften (Berlin). (*Follows the* "Berichte" *and is followed by the* "Sitzungsberichte.")
552. Rensselaer Polytechnic Institute, Engineering and Science Series.
553. Cosmos. Revue encyclopédique hebdomadaire des progrès des sciences. *United with* Cosmos: Les mondes, revue hebdomadaire des sciences *to form* Cosmos: Revue des sciences et leurs applications.

B1. Hund, Linienspektren und periodisches System der Elemente. Berlin, Springer, 1917.
B2. Glazebrook, R. T., Dictionary of Applied Physics. London, Macmillan, 1922–23.
B3. Landolt-Börnstein, Physikalisch-chemische Tabellen. 5th ed. Berlin, Springer, 1923.
B7. Peek, F. W., Dielectric Phenomena in High Voltage Engineering. New York, McGraw-Hill, 1920.
B13. Nernst Festschrift, 1912. Knapp, Halle.
B60. Fourth International Congress of Refrigeration, Reports. Papers presented by the President. Leiden, Ijdo, 1924.
B62. Henning, Die Grundlagen, Methoden und Ergebnisse der Temperaturmessung. Braunschweig, Vieweg, 1915.
B63. Holborn, Scheel and Henning, Wärmetabellen. Braunschweig, Vieweg, 1919.
B76. Winkelmann, Handbuch der Physik. Leipzig, Barth, 1903–09.
B78. Siegbahn, Spektroskopie der Röntgenstrahlen. Berlin, Springer, 1924. English ed., The Spectroscopy of X-Rays. London, Oxford Univ. Press, 1925.
B87. Guerther, Metallographie. Berlin, Borntraeger, 1909–
B88. Marx, Handbuch der Radiologie. Akademische Verlagsgesellschaft m. b. H., Leipzig, 1925.
B89. Richardson, Emission of Electricity from Hot Bodies. New York, Longmans, 1921.
B90. Graetz, Handbuch der Elektrizität und Magnetismus. Leipzig, Barth, 1912–28.
B91. Sosman, The Properties of Silica. New York, Chemical Catalog Co., 1927.
B94. Sommerfeld, Atombau und Spektrallinien. Braunschweig, Vieweg, 1924.
B95. Geiger and Scheel, Handbuch der Physik. Berlin, Springer, 1926–
B98. Sonderabdruck aus der Festschrift zur Feier des siebzigsten Geburtstages Richard Dedekind. Braunschweig, Vieweg, 1901.
B101. de Broglie, Les Rayons-X. Paris, Blanchard, 1922.

BIBL. LOND. UNIV.